

Research Article

Analytical Investigation on Hybrid Triple Skinned CFST Under the Effect of Sudden Impact

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Abstract: This paper is a continuation of the researches which were carried out by [1-3]. Accordingly, this manuscript proposes analytical analysis of a novel triple skin Concrete Filled Steel Tube (CFST) under the effect of sudden impact. Moreover, this is done by extending the double skinned CFST design and installing a third inner CFST inside the second inner tube to achieve the proposed triple skinned CFST design. Furthermore, the propositions consist of two parts. Where the first proposition is a novel triple skin CFST design under the effect of sudden impact, with first sandwich layer filled with Ultra High-Performance Fiber Reinforced Concrete (UHPFRC) and second sandwich layer filled with Normal Strength Concrete (NSC). While the second proposition is a novel triple skin CFST under the effect of sudden impact, with first sandwich layer filled with UHPFRC, second sandwich layer filled with NSC and third skin internal tube filled with NSC. It is strongly believed by the author of this manuscript that (1) the first proposition of novel triple skin CFST will increase the impact resistivity of the structural member by 25 to 32% and (2) it is predicted that the second proposition of novel triple skin CFST will boost the efficiency of the structural member under the even of sudden impact by 28 to 36%.

Keywords: Analytical investigation; Hybrid; Triple Skin; CFST; Sudden Impact

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1. Introduction

The first part of this paper discusses the Geometrical properties, material properties, cross sectional dimensions, boundary conditions and impact loading conditions of CFDST and CFTST columns. While, the second part debates the Numerical analysis and testing procedure of the models subjected to transverse impact loading. Moreover, the third part of this manuscript demonstrates an overview of the proposed modifications by [1-3]. This is including (1) Concrete Filled Double skin Steel Tubular members under transverse impact load investigation carried out by [19], (2) First Proposed modification by [1-3] - CFDST with internal carbon steel tube filled with NSC, (3) Second proposed modification by [1-3] - CFDST with 1st sandwich layer filled with UHPFRC and (4) Third proposed modification by [1-3] - CFDST with 1st sandwich layer filled with UHPFRC and internal carbon steel tube filled with NSC. Furthermore, the fourth part of this paper will deliberate the author propositions of novel triple skin CFST under the effect of sudden impact. Such as, (a) the first proposition of novel triple skin CFST under the effect of sudden impact - CFTST with 1st sandwich layer filled with UHPFRC and 2nd sandwich layer filled with NSC and (b) the second proposition of novel triple skin CFST under the effect of sudden impact - CFTST with 1st sandwich layer filled with UHPFRC, 2nd sandwich layer filled with NSC and 3rd skin internal tube filled with NSC. Finally, but never the least, the conclusion and recommendations for future work will be given based on the novel propositions of triple skin CFST under the effect of sudden impact.

2. Geometrical properties, material properties, cross sectional dimensions, boundary conditions and impact loading conditions of CFDST and CFTST columns

The geometry of all the numerical models will be circular in accordance to the ones used by [19]. Moreover, the cross-sectional dimensions for all the simulated numerical models has been presented in Tables 1, 2, 3, 4, 5, 6 and 7. Furthermore, there should be a total of six materials which will be used in all the proposed models. These are two types of steel (stainless steel and carbon steel), two types of concrete filling (Normal Strength Concrete (NSC) and Ultra High-Performance Fiber Reinforced Concrete (UHPFRC)) and Glass Fiber Reinforced Polymer (GFRP) with the bonding adhesive. Besides, the material properties of steel by [19] has been presented in Table 1. In addition, Table 2 shows the material properties of concrete used by [15-16] and [19]. Also, the material properties of GFRP and bonding adhesive by [4] has been illustrated in Table 3. Moreover, fixed to fixed boundary conditions at both ends should be used in all the proposed numerical models in accordance to the boundary condition used by [19]. Furthermore, the impact loading conditions for all the simulations of the proposed numerical models has been illustrated in Tables 4, 5, 6, 7, 8 and 9.

Table 1. Material properties of steel by [19].

Steel type	T _s (mm)	f _y (MPa)	f _u (MPa)	E _s (MPa)	δ
Stainless steel	1.88	322.1	702.5	1.91×10 ⁵	0.464
Carbon Steel	2.01	274.6	350.5	2.08×10 ⁵	0.218
	2.52	276.3	384.3	2.05×10 ⁵	0.252

Table 2. Material properties of concrete by [19] and [15-16].

Researcher	Concrete Type	f _{cu,28d} (MPa)	f _{cu,test} (MPa)	E _{c,test} (MPa)
Zhao et al. (2019)	Normal Strength Concrete (NSC)	55.3	60.2	3.1×10 ⁴
Wang et al. (2019)	UHPFRC	152	-	-

Table 3. Material properties of GFRP and bonding adhesive by [4].

FRP Type	Elastic Modulus (GPa)	Tensile Strength (MPa)	Thickness of FRP (mm)
GFRP	23	508	0.49
Adhesive	3	46	Assumed 0.16

The numerical analysis consists from six stages. These are the main design by [19], three design proposals by [1-3] and two design propositions of novel triple skin CFST. Furthermore, each stage involves eighteen numerical simulations. Moreover, all the numerical models will be built and analyses using Abaqus Finite Element Analysis (FEA) software package in accordance to the below user manuals:

- ABAQUS/Explicit User's Manual (version 6.5.1) by Karlsson Sorensen Inc. (2005) [10].

- ABAQUS Standard User's Manual (version 6.7) by Dassault Systèmes Corp (2007) [6].
- ABAQUS Standard User's manual (version 6.10) by Hibbitt, Karlsson and Sorensen Inc. (2010) [8].

3. Numerical analysis and testing procedure of the models subjected to transverse impact loading

All the proposed numerical models should be built and analyzed using Abaqus Finite Element Analysis software package as recommended by [19]. Moreover, all the experimental testing features which were performed by [19] should be taken into consideration in the numerical analysis models. This is including the connection between the concrete filling and the stainless steel and carbon steel tubes. Also, the proposed models should be subjected to the same magnitudes of the combined static axial and dynamic impact loads as per the tested specimens by [19]. Furthermore, the following Stress-Strain models were reformed in accordance to the [19]:

- 2 Stage Stress-Strain model for stainless steel.
- 5 Stage Stress-Strain model for carbon steel.

Again with reference to [19] the rate of strain of the dependent model for the yield strength of stainless steel was not defined. However, the below Cowper-Symonds model equation 1 could be used to calculate the strain-rate dependencies of yield strength for stainless and carbon steels:

$$\frac{f_y^d}{f_y} = 1 + \left(\frac{\dot{\epsilon}}{D}\right)^{1/p}, \quad (1)$$

Where f_y^d is the dynamic yield stress at strain rate $\dot{\epsilon}$, f_y represents the static yield stress, D is a factor and was chosen to have a value of 6844 s^{-1} , while p is another factor with a value of 3.91 in accordance to the factors values used by [14]. In order to numerically simulate the behavior of concrete fill under impact loading, the "concrete damaged plasticity model" tool should use with compressive crushing and tensile cracking mechanisms in accordance to [5], [9], [12], [13], [14], [17] and [19]. Furthermore, the confinement of the concrete fill sandwich layer and the concrete core should be defined as "compressive stress-strain model". Besides, the concrete fill in tension should be modeled using "linear stress-strain model" in accordance to the investigation carried out by [11]. Moreover, the main models' parameters such as (1) the ratio of the compressive strength in the biaxial state to uniaxial compressive strength, (2) viscosity, (3) eccentricity, (4) K-parameter and (5) dilation angle should be adjusted at magnitudes of 1.16, 0, 0.1, 0.667 and 30° respectively. On the other hand, the tensile damage variable (dt) and the compressive damage variable (dc) should not be assigned in the analysis.

The numerical analysis for all the proposed models should go through the below defined stages:

- "Elastic spring model" was used which represents the static axial load on the models.
- The dynamic transverse load should be initiated by positioning the drop hammer near to the numerical sample models. Also, the initial velocity for each simulation should be set depending on the drop height.
- All the analyzed models should be subjected to the gravity acceleration (g) command.

- “Hard contact friction model” should be assigned in the normal direction and “Coulomb friction model” should be assigned in the tangential direction in order to have a realistic interaction response between the steel tubes and the concrete sandwich layers.
- The friction coefficient for stainless steel tube and concrete interface should be assigned at 0.25. While, the friction coefficient for carbon steel tube and concrete interface should be assigned at 0.6 with reference to the studies conducted by [7] and [18].

4. Overview of the proposed modifications by Abdel Rahim (2021)

This section of this paper will review (1) Concrete Filled Double skin Steel Tubular members under transverse impact load investigation carried out by [19], (2) First Proposed modification by [1-3] - CFDST with internal carbon steel tube filled with NSC, (3) Second proposed modification by [1-3] - CFDST with 1st sandwich layer filled with UHP-FRC and (4) Third proposed modification by [1-3] - CFDST with 1st sandwich layer filled with UHPFRC and internal carbon steel tube filled with NSC.

4.1. Concrete Filled Double skin Steel Tubular members under transverse impact load investigation carried out by Zhao et al. (2019)

[1-3] has conducted the first stage of the numerical analysis by modelling and evaluating the CFDST specimens which were carried out by [19]. Moreover, the results obtained by [1-3] were compared with the experimental results achieved by [19] for validation purposes and to develop the first proposed design. As shown in Table 4, eighteen numerical models (simulation numbers 1 to 18) has been evaluated by [1-3] without any modifications on the tested specimens by [19]. Furthermore, three main variables were evaluated (hollowness ratio, magnitude of axial load and drop height). In addition, Table 4 presents a detailed list of geometrical properties, cross sectional dimensions and impact loading conditions for CFDST specimens by [19]. Besides, the list which presented in Table 4 includes details of the simulation numbers, specimens tag numbers, type of modification for this stage, diameter and thickness of the steel tubes, length of the specimens, magnitude of axial load, drop heights, impact mass, impact energy and geometry and size of indenter.

Table 4. List of geometrical properties, cross sectional dimensions and impact loading conditions for CFDST specimens by [19].

Simulation number	Specimen Tag number	Outer 1st layer Stainless Steel tube		Inner 2nd layer Carbon Steel tube		Inner 3rd layer Carbon Steel tube		L (mm)	Axially Loaded	Magnitude of axial load (kN)	H (m)	M0 (kg)	E0 (kJ)
		D (mm)	ts (mm)	D (mm)	ts (mm)	D (mm)	ts (mm)						
1	L-3-0-a	114	1.88	48	2.52	N/A	N/A	1800	No	0	3	203.7	6
2	L-3-0-b	114	1.88	48	2.52	N/A	N/A		No	0	3		6
3	L-5-0.5-a	114	1.88	48	2.52	N/A	N/A		Yes	343	5		10
4	L-5-0.5-b	114	1.88	48	2.52	N/A	N/A		Yes	343	5		10
5	L-7-0.3-a	114	1.88	48	2.52	N/A	N/A		Yes	206	7		14
6	L-7-0.3-b	114	1.88	48	2.52	N/A	N/A		Yes	206	7		14
7	M-3-0.5-a	114	1.88	76	2.01	N/A	N/A		Yes	317	3		6
8	M-3-0.5-b	114	1.88	76	2.01	N/A	N/A		Yes	317	3		6
9	M-5-0.3-a	114	1.88	76	2.01	N/A	N/A		Yes	190	5		10
10	M-5-0.3-b	114	1.88	76	2.01	N/A	N/A		Yes	190	5		10
11	M-7-0-a	114	1.88	76	2.01	N/A	N/A		No	0	7		14
12	M-7-0-b	114	1.88	76	2.01	N/A	N/A		No	0	7		14
13	H-3-0.3-a	114	1.88	89	2.01	N/A	N/A		Yes	142	3		6
14	H-3-0.3-b	114	1.88	89	2.01	N/A	N/A		Yes	142	3		6
15	H-5-0-a	114	1.88	89	2.01	N/A	N/A		No	0	5		10
16	H-5-0-b	114	1.88	89	2.01	N/A	N/A		No	0	5		10
17	H-7-0.5-a	114	1.88	89	2.01	N/A	N/A		Yes	237	7		14
18	H-7-0.5-b	114	1.88	89	2.01	N/A	N/A		Yes	237	7		14

No Modification - Modelling the same models as [19] and analyzing them for comparing the results.
 Impactor/Indenter geometry and size - drop hammer with 30mm×80mm rectangular bottom surface.

A schematic drawing has been shown in Figure 1 of the CFDST cross section and material properties for specimens with hollowness ratio of 0.44 by [19]. As can be seen in Figure 1, the model consists of two steel tubes. The 1st layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 48mm and a thickness of 2.52mm. Furthermore, there will be one Normal Strength Concrete (NSC) fill sandwich layer with a compressive strength of 55.3MPa between the outer and the inner steel tubes. On the contrary, the inner carbon steel tube will be hollow/unfilled. Moreover, all the specimens had a standard length of 1800mm.

This design in figure 1 by [19] will represent simulation numbers 1 to 6 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 1 and 2 has not been axially load, the drop height has been set at 3m and the impact energy will be 6kJ. While numbers 3 and 4 has been axially loaded with a magnitude of 343kN, the drop height has been set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 5 and 6 has been axially loaded with a magnitude of 206kN, the drop height has been set at 7m and the impact energy will be 14kJ. Moreover,

the drop mass will have the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

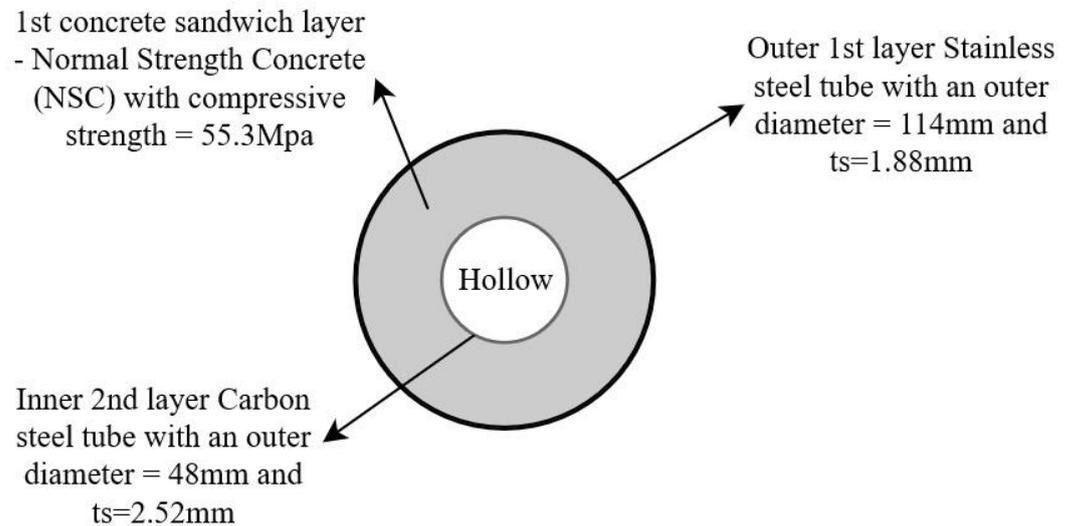


Figure 1. Schematic sketch of the CFDST cross section and material properties for specimens with hollowness ratio of 0.44 by [19].

A schematic drawing has been shown in Figure 2 of the CFDST cross section and material properties for specimens with hollowness ratio of 0.69 by [19]. As can be seen in Figure 2, the model consisted of two steel tubes. The 1st layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 76mm and a thickness of 2.01mm. Furthermore, there will be one Normal Strength Concrete (NSC) fill sandwich layer with a compressive strength of 55.3MPa between the outer and the inner steel tubes. On the contrary, the inner carbon steel tube will be hollow/unfilled. Moreover, all the specimens had a standard length of 1800mm.

This design in figure 2 by [19] represented simulation numbers 7 to 12 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 7 and 8 has been axially load with a magnitude of 317kN, the drop height has been set at 3m and the impact energy will be 6kJ. While simulation numbers 9 and 10 has been axially loaded with a magnitude of 190kN, the drop height has been set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 11 and 12 were not axially loaded, the drop height has been set at 7m and the impact energy will be 14kJ. Moreover, the drop mass had the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

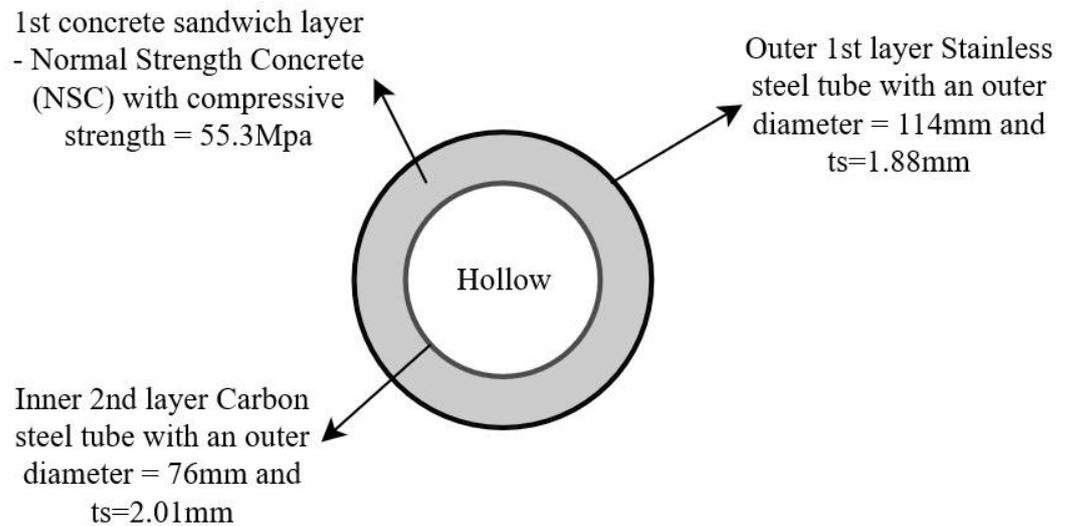


Figure 2. Schematic sketch of the CFDST cross section and material properties for specimens with hollowness ratio of 0.69 by [19].

A schematic drawing has been shown in Figure 3 of the CFDST cross section and material properties for specimens with hollowness ratio of 0.81 by [19]. As can be seen in Figure 3, the model consists of two steel tubes. The 1st layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 89mm and a thickness of 2.01mm. Furthermore, there will be one Normal Strength Concrete (NSC) fill sandwich layer with a compressive strength of 55.3MPa between the outer and the inner steel tubes. On the contrary, the inner carbon steel tube will be hollow/un-filled. Moreover, all the specimens had a standard length of 1800mm.

This design in figure 3 by [19] represented simulation numbers 13 to 18 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 13 and 14 were axially load with a magnitude of 142kN, the drop height has been set at 3m and the impact energy will be 6kJ. While simulation numbers 15 and 16 were not axially loaded, the drop height was set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 17 and 18 were axially loaded with a magnitude of 237kN, the drop height was set at 7m and the impact energy will be 14kJ. Moreover, the drop mass had the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

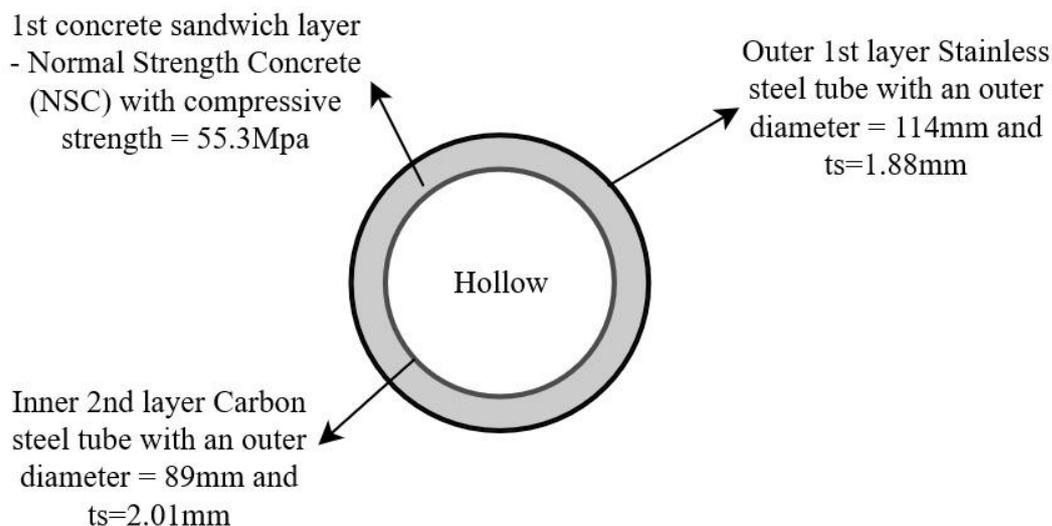


Figure 3. Schematic sketch of the CFDST cross section and material properties for specimens with hollowness ratio of 0.81 by [19].

This subsection of the numerical analysis will present the meshing and elements for Concrete Filled Double skin Steel Tubular members under transverse impact load investigation in accordance to the properties stated by [19] in terms of CFDST element, supports, drop hammer and FE model. The numerical meshing and elements of the first modeling analysis part for the Concrete Filled Double skin Steel Tubular members under transverse impact load investigation has been in accordance to the properties stated by [19]. Accordingly, the mesh for both the outer first layer stainless steel tube and the inner second layer carbon steel tube were simulated using S4R 4-node shell elements. While the mesh for concrete fill sandwich between the outer and the inner steel tubes was simulated using C3D8R 8-node solid element. With reference to [19], the mesh for supports has been built using R3D4 4-node quadrilateral rigid element. Again, as recommended by [19], the mesh for drop hammer were built using R3D4 4-node quadrilateral rigid element.

4.2. First Proposed modification by Abdel Rahim (2021) - CFDST with internal carbon steel tube filled with NSC

The second stage of the numerical analysis involves the first proposed modification by [1-3] on CFDST specimens which were carried out by [19]. This was done by filling the internal carbon steel tube with Normal Strength Concrete (NSC) and evaluating the structural behavior under impact loading. Moreover, the results obtained [1-3] has been compared with the experimental results achieved by [19] to determine the percentage of increase in the impact resistivity of the first proposed design. As shown in Table 5, the second stage of this study consists of eighteen numerical models (simulation numbers 19 to 36) has been evaluated with a minor modification (filling the internal carbon steel tube with NSC) on the tested specimens by [19]. Again, three main variables have been evaluated (diameter of internal carbon steel tube, magnitude of axial load and drop height). In addition, Table 5 presents a detailed list of geometrical properties, cross sectional dimensions and impact loading conditions for the first proposed modification on the CFDST specimens carried out by [19]. Besides, the list which presented in Table 5 includes details of the simulation numbers, specimens tag numbers, type of modification for this stage, diameter and thickness of the steel tubes, length of the specimens, magnitude of axial load, drop heights, impact mass, impact energy and geometry and size of indenter.

Table 5. List of geometrical properties, cross sectional dimensions and impact loading conditions for CFDST specimens with First Proposed modification by [1-3].

Simulation number	Specimen Tag number	Outer 1st layer Stainless Steel tube		Inner 2nd layer Carbon Steel tube		Inner 3rd layer Carbon Steel tube		L (mm)	Axially Loaded	Magnitude of axial load (kN)	H (m)	M0 (kg)	E0 (kJ)
		D (mm)	ts (mm)	D (mm)	ts (mm)	D (mm)	ts (mm)						
19	L-3-0-a-M1	114	1.88	48	2.52	-	-	1800	No	0	3	203.7	6
20	L-3-0-b-M1	114	1.88	48	2.52	-	-		No	0	3	203.7	6
21	L-5-0.5-a-M1	114	1.88	48	2.52	-	-		Yes	343	5	203.7	10
22	L-5-0.5-b-M1	114	1.88	48	2.52	-	-		Yes	343	5	203.7	10
23	L-7-0.3-a-M1	114	1.88	48	2.52	-	-		Yes	206	7	203.7	14
24	L-7-0.3-b-M1	114	1.88	48	2.52	-	-		Yes	206	7	203.7	14
25	M-3-0.5-a-M1	114	1.88	76	2.01	-	-		Yes	317	3	203.7	6
26	M-3-0.5-b-M1	114	1.88	76	2.01	-	-		Yes	317	3	203.7	6
27	M-5-0.3-a-M1	114	1.88	76	2.01	-	-		Yes	190	5	203.7	10
28	M-5-0.3-b-M1	114	1.88	76	2.01	-	-		Yes	190	5	203.7	10
29	M-7-0-a-M1	114	1.88	76	2.01	-	-		No	0	7	203.7	14
30	M-7-0-b-M1	114	1.88	76	2.01	-	-		No	0	7	203.7	14
31	H-3-0.3-a-M1	114	1.88	89	2.01	-	-		Yes	142	3	203.7	6
32	H-3-0.3-b-M1	114	1.88	89	2.01	-	-		Yes	142	3	203.7	6
33	H-5-0-a-M1	114	1.88	89	2.01	-	-		No	0	5	203.7	10
34	H-5-0-b-M1	114	1.88	89	2.01	-	-		No	0	5	203.7	10
35	H-7-0.5-a-M1	114	1.88	89	2.01	-	-		Yes	237	7	203.7	14
36	H-7-0.5-b-M1	114	1.88	89	2.01	-	-		Yes	237	7	203.7	14

Modification 1 - Fill Inner 2nd layer Carbon Steel tube with NSC

Impactor/Indenter geometry and size - drop hammer with 30mm×80mm rectangular bottom surface.

A schematic drawing has been shown in Figure 4 of the CFDST cross section with first modification and material properties for specimens with 48mm outer diameter of the internal tube. As can be seen in Figure 4, the model consisted of two steel tubes. The 1st layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 48mm and a thickness of 2.52mm. Furthermore, there will be one Normal Strength Concrete (NSC) fill sandwich layer with a compressive strength of 55.3MPa between the outer and the inner steel tubes. In addition, the inner carbon steel tube has been also filled with Normal Strength Concrete (NSC) with a compressive strength of 55.3MPa. Moreover, all the numerically analyzed specimens had a standard length of 1800mm.

This proposed modification design in figure 4 represented simulation numbers 19 to 24 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 19 and 20 were not axially load, the drop height was set at 3m and the impact energy will be 6kJ. While simulation numbers 21 and 22 were axially loaded with a magnitude of 343kN, the drop height was set at 5m and the impact energy will be

around 10kJ. Furthermore, simulation numbers 23 and 24 were axially loaded with a magnitude of 206kN, the drop height was set at 7m and the impact energy will be 14kJ. Moreover, the drop mass had the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

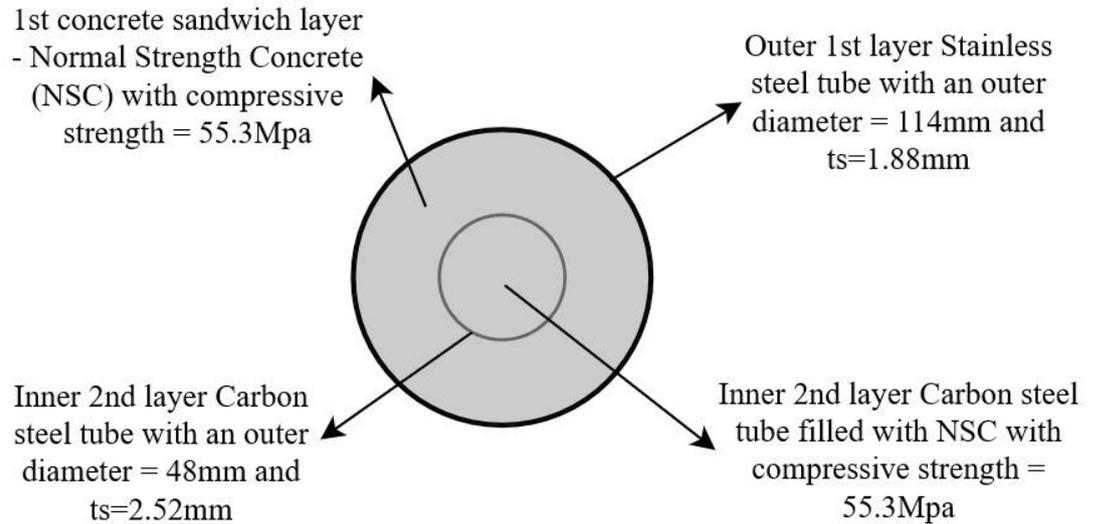


Figure 4. Schematic sketch of CFDST cross section with 1st modification by [1-3] and material properties for specimens with 48mm outer diameter of the internal tube.

A schematic drawing has been shown in Figure 5 of the CFDST cross section with first modification and material properties for specimens with 76mm outer diameter of the internal tube. As can be seen in Figure 5, the model consisted of two steel tubes. The first layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 76mm and a thickness of 2.01mm. Furthermore, there will be one Normal Strength Concrete (NSC) fill sandwich layer with a compressive strength of 55.3MPa between the outer and the inner steel tubes. In addition, the inner carbon steel tube has been also filled with Normal Strength Concrete (NSC) with a compressive strength of 55.3MPa. Moreover, all the numerically analyzed specimens had a standard length of 1800mm.

This design modification in figure 5 will represent simulation numbers 25 to 30 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 25 and 26 will be axially load with a magnitude of 317kN, the drop height will be set at 3m and the impact energy will be 6kJ. While simulation numbers 27 and 28 will be axially loaded with a magnitude of 190kN, the drop height will be set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 29 and 30 will not be axially loaded, the drop height will be set at 7m and the impact energy will be 14kJ. Moreover, the drop mass will have the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

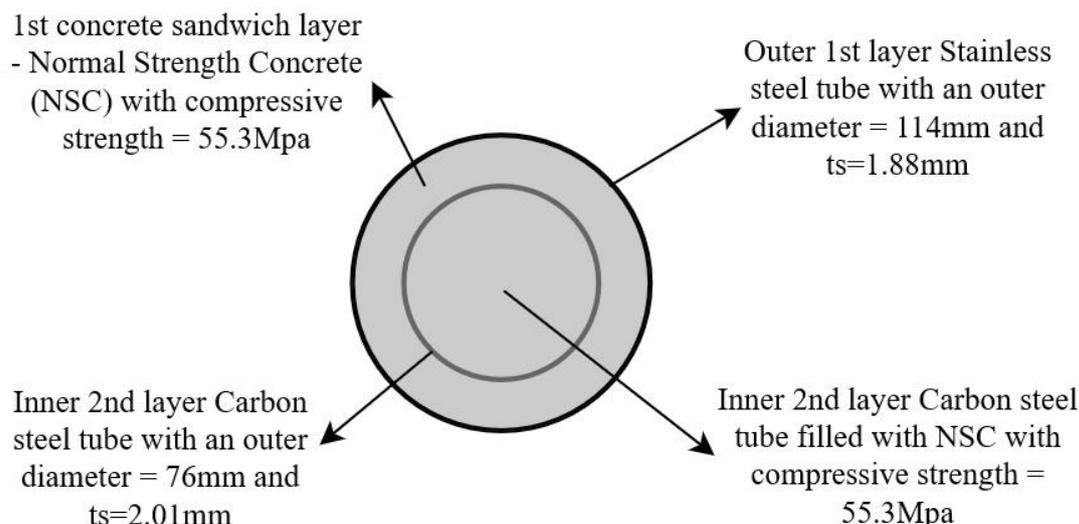


Figure 5. Schematic sketch of CFDSST cross section with 1st modification by [1-3] and material properties for specimens with 76mm outer diameter of the internal tube.

A schematic drawing has been shown in Figure 6 of the CFDSST cross section with first modification and material properties for specimens with 89mm outer diameter of the internal tube. As can be seen in Figure 6, the model consisted of two steel tubes. The first layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 89mm and a thickness of 2.01mm. Furthermore, there will be one Normal Strength Concrete (NSC) fill sandwich layer with a compressive strength of 55.3MPa between the outer and the inner steel tubes. In addition, the inner carbon steel tube was also filled with Normal Strength Concrete (NSC) with a compressive strength of 55.3MPa. Moreover, all the numerically analyzed specimens had a standard length of 1800mm.

This design modification in figure 6 will represent simulation numbers 31 to 36 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 31 and 32 will be axially load with a magnitude of 142kN, the drop height will be set at 3m and the impact energy will be 6kJ. While simulation numbers 33 and 34 will not be axially loaded, the drop height will be set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 35 and 36 will be axially loaded with a magnitude of 237kN, the drop height will be set at 7m and the impact energy will be 14kJ. Moreover, the drop mass will have the same magnitude for all the simulations with a value of 203.7Kg. Additionally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

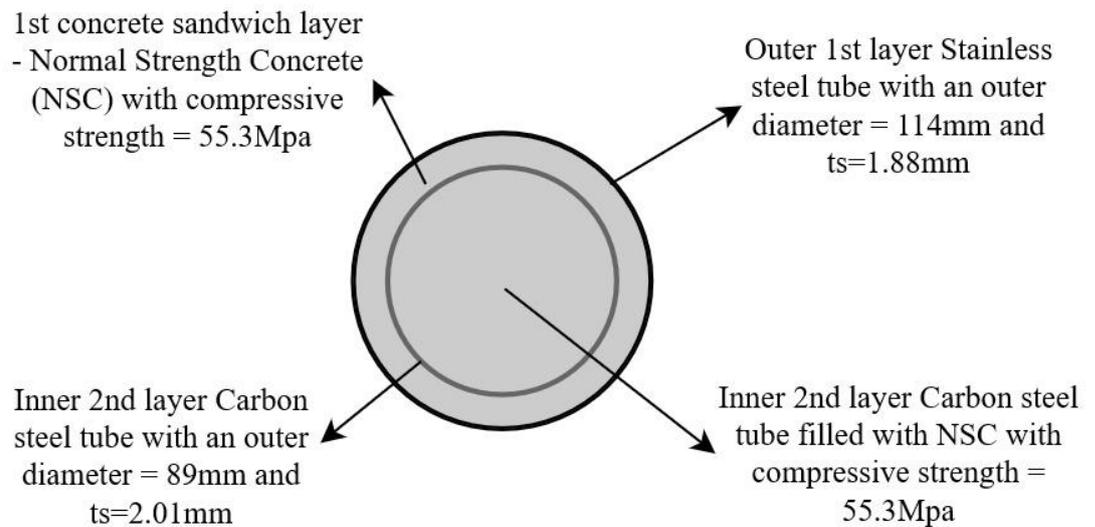


Figure 6. Schematic sketch of CFDST cross section with 1st modification by [1-3] and material properties for specimens with 89mm outer diameter of the internal tube.

This subsection of the numerical analysis will present the meshing and elements for Concrete Filled Double skin Steel Tubular column members with internal carbon steel tube filled with NSC under transverse impact load investigation in accordance to the properties stated by [19]. In addition, the meshing illustrations will be shown in terms of CFDST element, supports, drop hammer and FE model. The numerical meshing and elements of the second modeling analysis part for the proposed modification 1 by [1-3] - CFDST with internal carbon steel tube filled with NSC under transverse impact load investigation has been as follows:

- The mesh for both the outer first layer stainless steel tube and the inner second layer carbon steel tube has been simulated using S4R 4-node shell elements.
- The mesh for both the first Normal Strength Concrete (NSC) fill sandwich layer and the inner second Normal Strength Concrete (NSC) fill sandwich layer (NSC) has been simulated using C3D8R 8-node solid element.

With reference to [19], the mesh for supports has been built using R3D4 4-node quadrilateral rigid element. Again, as recommended by [19], the mesh for drop hammer were built using R3D4 4-node quadrilateral rigid element.

4.3. Second proposed modification by Abdel Rahim (2021) - CFDST with 1st sandwich layer filled with UHPFRC

The third stage of the numerical analysis involves the second proposed modification by [1-3] on CFDST specimens which were carried out by [19]. This is by filling the 1st sandwich layer between the outer and the internal steel tubes with Ultra High-Performance Fiber Reinforced Polymer (UHPFRC) and evaluating the structural behavior under impact loading. Moreover, the results obtained by [1-3] has been compared with the experimental results achieved by [19] to determine the percentage of increase in the impact resistivity of the second proposed design. As shown in Table 6, the third stage of this study consisted of eighteen numerical models (simulation numbers 37 to 54) were evaluated with a minor modification (filling the internal carbon steel tube with UHPFRC) on the tested specimens by [19]. Again, three main variables were evaluated (diameter of internal carbon steel tube, magnitude of axial load and drop height). In addition, Table 6 presents a detailed list of geometrical properties, cross sectional dimensions and impact loading

conditions for the second proposed modification on the CFDST specimens carried out by [19]. Besides, the list which presented in Table 6 includes details of the simulation numbers, specimens tag numbers, type of modification for this stage, diameter and thickness of the steel tubes, length of the specimens, magnitude of axial load, drop heights, impact mass, impact energy and geometry and size of indenter.

Table 6. List of geometrical properties, cross sectional dimensions and impact loading conditions for CFDST specimens with second proposed modification by [1-3].

Simulation number	Specimen Tag number	Outer 1st layer Stainless Steel tube		Inner 2nd layer Carbon Steel tube		Inner 3rd layer Carbon Steel tube		L (mm)	Axially Loaded	Magnitude of axial load (kN)	H (m)	M0 (kg)	E0 (kJ)
		D (mm)	ts (mm)	D (mm)	ts (mm)	D (mm)	ts (mm)						
37	L-3-0-a-M2	114	1.88	48	2.52	-	-	1800	No	0	3	203.7	6
38	L-3-0-b-M2	114	1.88	48	2.52	-	-		No	0	3	203.7	6
39	L-5-0.5-a-M2	114	1.88	48	2.52	-	-		Yes	343	5	203.7	10
40	L-5-0.5-b-M2	114	1.88	48	2.52	-	-		Yes	343	5	203.7	10
41	L-7-0.3-a-M2	114	1.88	48	2.52	-	-		Yes	206	7	203.7	14
42	L-7-0.3-b-M2	114	1.88	48	2.52	-	-		Yes	206	7	203.7	14
43	M-3-0.5-a-M2	114	1.88	76	2.01	-	-		Yes	317	3	203.7	6
44	M-3-0.5-b-M2	114	1.88	76	2.01	-	-		Yes	317	3	203.7	6
45	M-5-0.3-a-M2	114	1.88	76	2.01	-	-		Yes	190	5	203.7	10
46	M-5-0.3-b-M2	114	1.88	76	2.01	-	-		Yes	190	5	203.7	10
47	M-7-0-a-M2	114	1.88	76	2.01	-	-		No	0	7	203.7	14
48	M-7-0-b-M2	114	1.88	76	2.01	-	-		No	0	7	203.7	14
49	H-3-0.3-a-M2	114	1.88	89	2.01	-	-		Yes	142	3	203.7	6
50	H-3-0.3-b-M2	114	1.88	89	2.01	-	-		Yes	142	3	203.7	6
51	H-5-0-a-M2	114	1.88	89	2.01	-	-		No	0	5	203.7	10
52	H-5-0-b-M2	114	1.88	89	2.01	-	-		No	0	5	203.7	10
53	H-7-0.5-a-M2	114	1.88	89	2.01	-	-		Yes	237	7	203.7	14
54	H-7-0.5-b-M2	114	1.88	89	2.01	-	-		Yes	237	7	203.7	14

Modification 2 - (1) Filling the sandwich layer between the Outer 1st layer Stainless Steel tube and the Inner 2nd layer Carbon Steel tube with UHPFRC & (2) keeping the Inner 2nd layer Carbon Steel tube hollow without concrete fill.

Impactor/Indenter geometry and size - drop hammer with 30mm×80mm rectangular bottom surface.

A schematic drawing has been shown in Figure 7 of the CFDST cross section with second modification and material properties for specimens with hollowness ratio of 0.44. As can be seen in Figure 7, the model consisted of two steel tubes. The 1st layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 48mm and a thickness of 2.52mm. Furthermore, there has been one Ultra High-Performance Fiber Reinforced Concrete (UHPFRC) fill sandwich layer with a

compressive strength of 152MPa between the outer and the inner steel tubes with reference to the material properties used by [15-16]. On the contrary, the inner carbon steel tube was hollow/unfilled. Moreover, all the numerically analyzed specimens had a standard length of 1800mm.

This design modification in figure 7 will represent simulation numbers 37 to 42 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 37 and 38 will be axially load with a magnitude of 142kN, the drop height will be set at 3m and the impact energy will be 6kJ. While simulation numbers 39 and 40 will not be axially loaded, the drop height will be set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 41 and 42 will be axially loaded with a magnitude of 237kN, the drop height will be set at 7m and the impact energy will be 14kJ. Moreover, the drop mass will have the same magnitude for all the simulations with a value of 203.7Kg. Additionally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

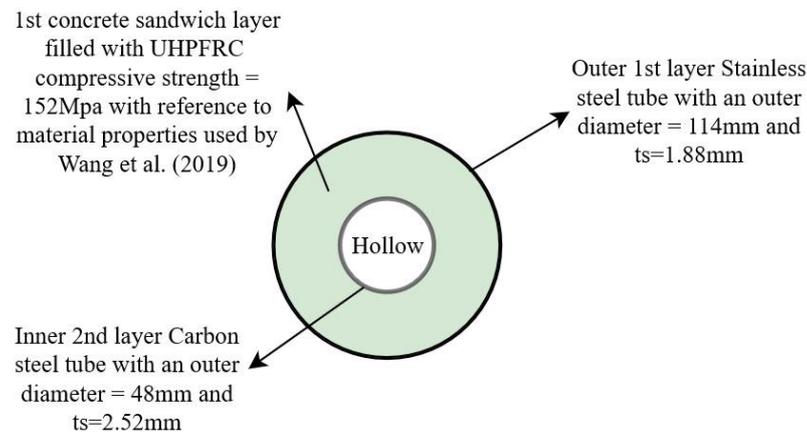


Figure 7. Schematic sketch of CFDST cross section with 2nd modification by [1-3] and material properties for specimens with hollowness ratio of 0.44.

A schematic drawing has been shown in Figure 8 of the CFDST cross section with second modification and material properties for specimens with hollowness ratio of 0.69. As can be seen in Figure 8, the model consisted from two steel tubes. The 1st layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 76mm and a thickness of 2.01mm. Furthermore, there has been one Ultra High-Performance Fiber Reinforced Concrete (UHPFRC) fill sandwich layer with a compressive strength of 152MPa between the outer and the inner steel tubes with reference to the material properties used by [15-16]. On the contrary, the inner carbon steel tube was hollow/unfilled. Moreover, all the numerically analyzed specimens had a standard length of 1800mm.

This design modification in figure 8 represented simulation numbers 43 to 48 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 43 and 44 were axially load with a magnitude of 317kN, the drop height has been set at 3m and the impact energy will be 6kJ. While simulation numbers 45 and 46 has been axially loaded with a magnitude of 190kN, the drop height has been set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 47 and 48 were not axially loaded, the drop height was set at 7m and the impact energy will be 14kJ. Moreover, the drop mass had the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

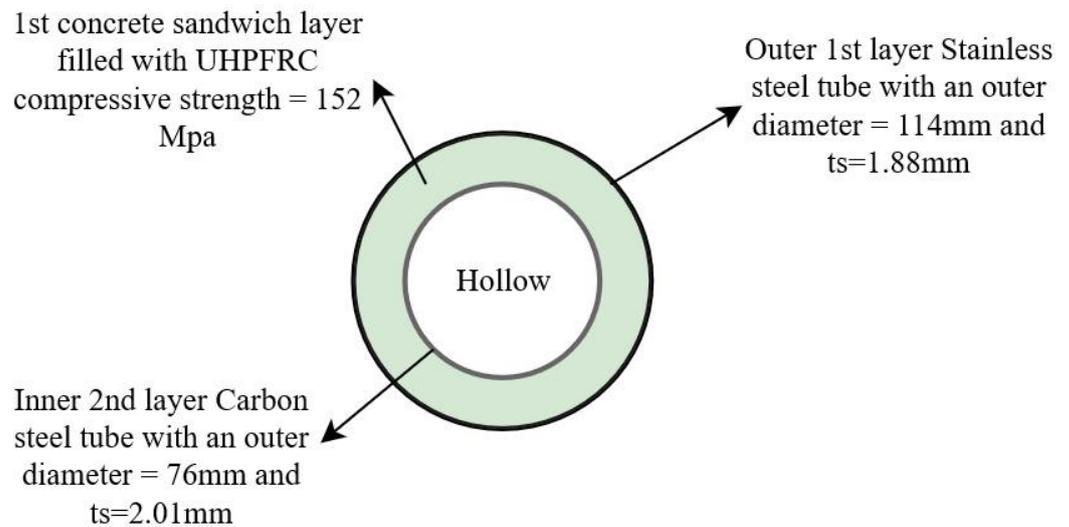


Figure 8. Schematic sketch of CFDSST cross section with 2nd modification by [1-3] and material properties for specimens with hollowness ratio of 0.69.

A schematic drawing has been shown in Figure 9 of the CFDSST cross section with second modification and material properties for specimens with hollowness ratio of 0.81. As can be seen in Figure 9, the model consisted of two steel tubes. The 1st layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 89mm and a thickness of 2.01mm. Furthermore, there has been one Ultra High-Performance Fiber Reinforced Concrete (UHPFRC) fill sandwich layer with a compressive strength of 152MPa between the outer and the inner steel tubes with reference to the material properties used by [15-16]. On the contrary, the inner carbon steel tube was hollow/unfilled. Moreover, all the numerically analyzed specimens had a standard length of 1800mm.

This design modification in figure 9 has been represented in simulation numbers 49 to 54 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 49 and 50 were axially load with a magnitude of 142kN, the drop height was set at 3m and the impact energy will be 6kJ. While simulation numbers 51 and 52 were not axially loaded, the drop height was set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 53 and 54 were axially loaded with a magnitude of 237kN, the drop height was set at 7m and the impact energy will be 14kJ. Moreover, the drop mass had the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

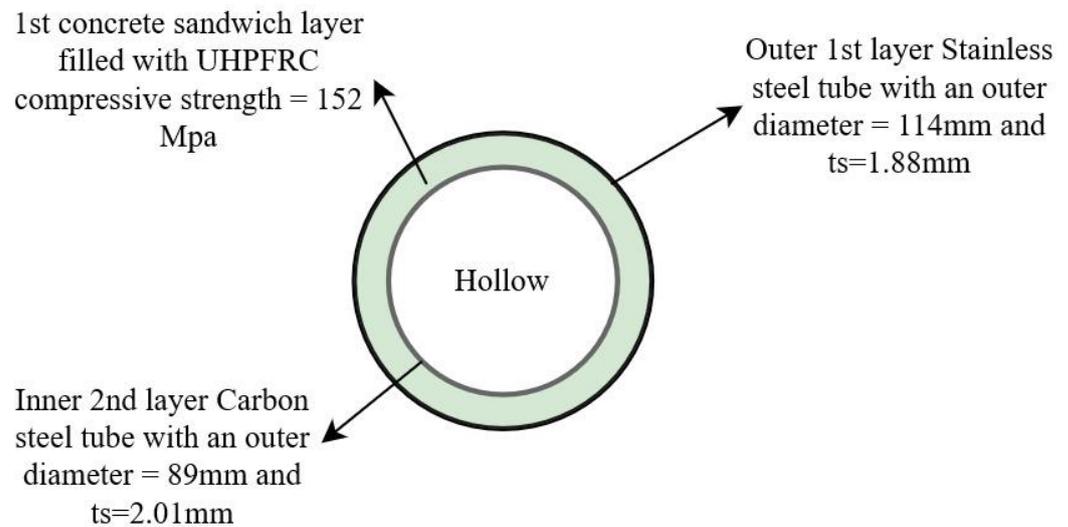


Figure 9. Schematic sketch of CFDST cross section with 2nd modification by [1-3] and material properties for specimens with hollowness ratio of 0.81.

This subsection of the numerical analysis presented the meshing and elements for Concrete Filled Double skin Steel Tubular column members with 1st sandwich layer filled with UHPFRC under transverse impact load investigation in accordance to the properties stated by [19]. This is including CFDST element, supports, drop hammer and FE model. The numerical meshing and elements of the third modeling analysis part for the proposed modification 2 - CFDST with 1st sandwich layer filled with UHPFRC under transverse impact load investigation has been as follows:

- The mesh for both the outer first layer stainless steel tube and the inner second layer carbon steel tube were simulated using S4R 4-node shell elements.
- The mesh for UHPFRC has been simulated using C3D8R 8-node solid element.

With reference to [19], the mesh for supports will be built using R3D4 4-node quadrilateral rigid element. Again, as recommended by [19], the mesh for drop hammer was built using R3D4 4-node quadrilateral rigid element.

4.4. Third proposed modification by Abdel Rahim (2021) - CFDST with 1st sandwich layer filled with UHPFRC and internal carbon steel tube filled with NSC

The fourth stage of the numerical analysis involves the third proposed modification on CFDST specimens which were carried out by [19]. This is by filling the 1st sandwich layer between the outer and the internal steel tubes with Ultra High-Performance Fiber Reinforced Polymer (UHPFRC). In addition, the internal carbon steel tube has been filled with Normal Strength Concrete (NSC). Afterwards, the structural behavior has been assisted under transverse impact loading. Moreover, the results obtained by [1-3] were compared with the experimental results achieved by [19] to determine the percentage of increase in the impact resistivity of the third proposed design. As shown in Table 7, the fourth stage of this study consisted of eighteen numerical models (simulation numbers 55 to 72). Again, three main variables were evaluated (diameter of internal carbon steel tube, magnitude of axial load and drop height). In addition, Table 7 presents a detailed list of geometrical properties, cross sectional dimensions and impact loading conditions for the third proposed modification on the CFDST specimens carried out by [19]. Besides, the list

which presented in Table 7 includes details of the simulation numbers, specimens tag numbers, type of modification for this stage, diameter and thickness of the steel tubes, length of the specimens, magnitude of axial load, drop heights, impact mass, impact energy and geometry and size of indenter.

Table 7. List of geometrical properties, cross sectional dimensions and impact loading conditions for CFDST specimens with Third proposed modification by [1-3].

Simulation number	Specimen Tag number	Outer 1st layer Stainless Steel tube		Inner 2nd layer Carbon Steel tube		Inner 3rd layer Carbon Steel tube		L (mm)	Axially Loaded	Magnitude of axial load (kN)	H (m)	M0 (kg)	E0 (kJ)
		D (mm)	ts (mm)	D (mm)	ts (mm)	D (mm)	ts (mm)						
55	L-3-0-a-M3	114	1.88	48	2.52	-	-	1800	No	0	3	203.7	6
56	L-3-0-b-M3	114	1.88	48	2.52	-	-		No	0	3	203.7	6
57	L-5-0.5-a-M3	114	1.88	48	2.52	-	-		Yes	343	5	203.7	10
58	L-5-0.5-b-M3	114	1.88	48	2.52	-	-		Yes	343	5	203.7	10
59	L-7-0.3-a-M3	114	1.88	48	2.52	-	-		Yes	206	7	203.7	14
60	L-7-0.3-b-M3	114	1.88	48	2.52	-	-		Yes	206	7	203.7	14
61	M-3-0.5-a-M3	114	1.88	76	2.01	-	-		Yes	317	3	203.7	6
62	M-3-0.5-b-M3	114	1.88	76	2.01	-	-		Yes	317	3	203.7	6
63	M-5-0.3-a-M3	114	1.88	76	2.01	-	-		Yes	190	5	203.7	10
64	M-5-0.3-b-M3	114	1.88	76	2.01	-	-		Yes	190	5	203.7	10
65	M-7-0-a-M3	114	1.88	76	2.01	-	-		No	0	7	203.7	14
66	M-7-0-b-M3	114	1.88	76	2.01	-	-		No	0	7	203.7	14
67	H-3-0.3-a-M3	114	1.88	89	2.01	-	-		Yes	142	3	203.7	6
68	H-3-0.3-b-M3	114	1.88	89	2.01	-	-		Yes	142	3	203.7	6
69	H-5-0-a-M3	114	1.88	89	2.01	-	-		No	0	5	203.7	10
70	H-5-0-b-M3	114	1.88	89	2.01	-	-		No	0	5	203.7	10
71	H-7-0.5-a-M3	114	1.88	89	2.01	-	-		Yes	237	7	203.7	14
72	H-7-0.5-b-M3	114	1.88	89	2.01	-	-		Yes	237	7	203.7	14

Modification 3 - (1) Filling the sandwich layer between the Outer 1st layer Stainless Steel tube and the Inner 2nd layer Carbon Steel tube with UHPFRC & (2) Filling the Inner 2nd layer Carbon Steel tube with NSC. Impactor/Indenter geometry and size - drop hammer with 30mm×80mm rectangular bottom surface.

A schematic drawing has been shown in Figure 10 of the CFDST cross section with 3rd modification and material properties for specimens with 48mm outer diameter of the internal tube. As can be seen in Figure 10, the model consisted of two steel tubes. The 1st layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 48mm and a thickness of 2.52mm. Furthermore, there was one Ultra High-Performance Fiber Reinforced Concrete (UHPFRC) fill sandwich layer with a compressive strength of 152MPa between the outer and the inner steel tubes with reference to the material properties used by [15-16]. Additionally, the inner

carbon steel tube was filled with Normal Strength Concrete (NSC) with a compressive strength of 55.3MPa. Moreover, all the numerically analyzed specimens had a standard length of 1800mm.

This proposed modification design in figure 10 represented simulation numbers 55 to 60 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 55 and 56 were not axially load, the drop height has been set at 3m and the impact energy will be 6kJ. While simulation numbers 57 and 58 were axially loaded with a magnitude of 343kN, the drop height was set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 59 and 60 were axially loaded with a magnitude of 206kN, the drop height was set at 7m and the impact energy will be 14kJ. Moreover, the drop mass had the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

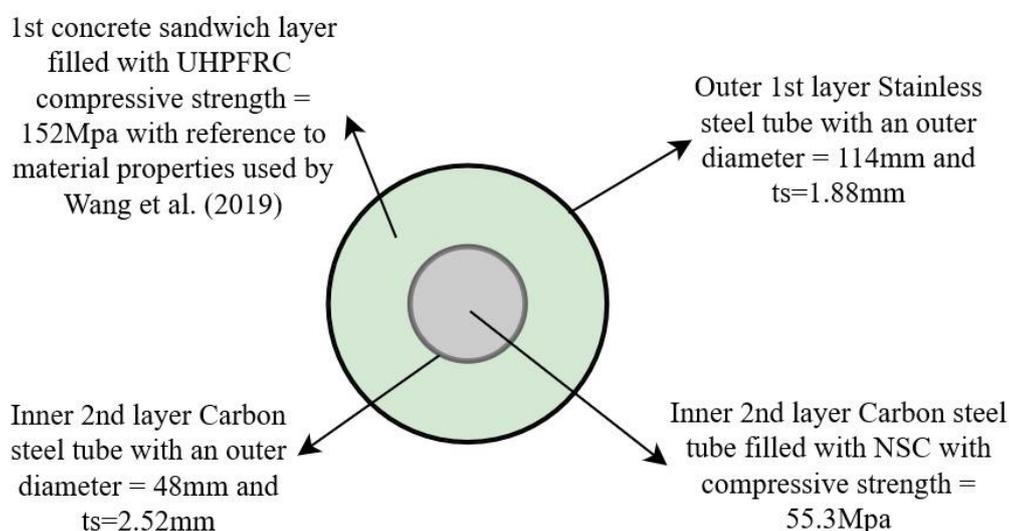


Figure 10. Schematic sketch of CFDST cross section with 3rd modification by [1-3] and material properties for specimens with 48mm outer diameter of the internal tube.

A schematic drawing has been shown in Figure 11 of the CFDST cross section with 3rd modification and material properties for specimens with 76mm outer diameter of the internal tube. As can be seen in Figure 11, the model consisted of two steel tubes. The 1st layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 76mm and a thickness of 2.01mm. Furthermore, there was one Ultra High-Performance Fiber Reinforced Concrete (UHPFRC) fill sandwich layer with a compressive strength of 152MPa between the outer and the inner steel tubes with reference to the material properties used by [15-16]. Additionally, the inner carbon steel tube has been filled with Normal Strength Concrete (NSC) with a compressive strength of 55.3MPa. Moreover, all the numerically analyzed specimens had a standard length of 1800mm.

This design modification in figure 11 represented simulation numbers 61 to 66 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 61 and 62 were axially load with a magnitude of 317kN, the drop height was set at 3m and the impact energy will be 6kJ. While simulation numbers 63 and 64 were axially loaded with a magnitude of 190kN, the drop height was set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 65 and 66 were not axially loaded, the drop height was set at 7m and the impact energy will be 14kJ. Moreover, the drop mass had the same magnitude for all the simulations with a value of 203.7Kg.

Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

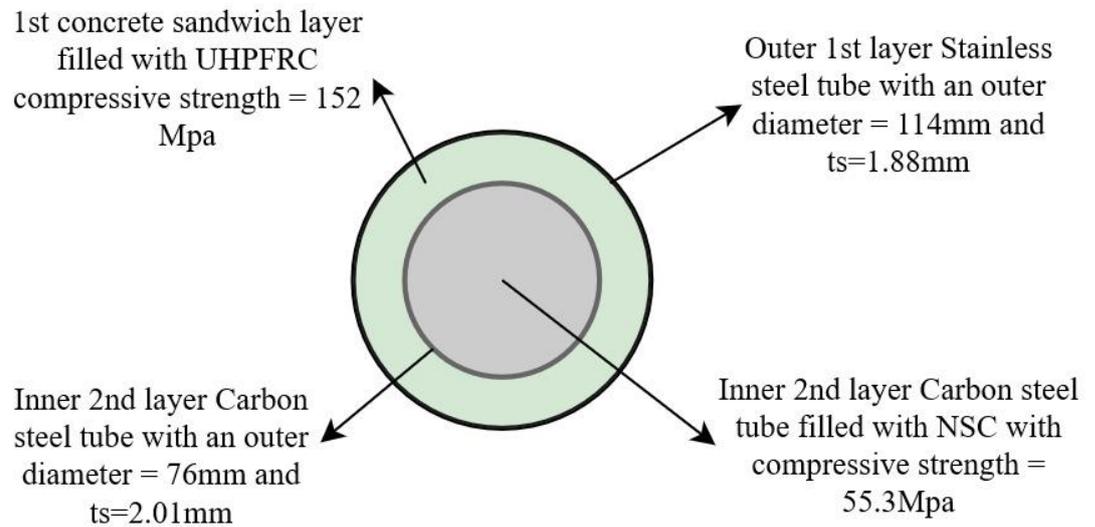


Figure 11. Schematic sketch of CFDSST cross section with 3rd modification by [1-3] and material properties for specimens with 76mm outer diameter of the internal tube.

A schematic drawing has been shown in Figure 12 of the CFDSST cross section with third modification and material properties for specimens with 89mm outer diameter of the internal tube. As can be seen in Figure 12, the model consisted of two steel tubes. The 1st layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second inner steel tube is made from carbon steel and an outer diameter of 89mm and a thickness of 2.01mm. Furthermore, there was one Ultra High-Performance Fiber Reinforced Concrete (UHPFRC) fill sandwich layer with a compressive strength of 152MPa between the outer and the inner steel tubes with reference to the material properties used by [15-16]. Additionally, the inner carbon steel tube was filled with Normal Strength Concrete (NSC) with a compressive strength of 55.3MPa. Moreover, all the numerically analyzed specimens had a standard length of 1800mm.

This design modification in figure 12 represented simulation numbers 67 to 72 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 67 and 68 were axially load with a magnitude of 142kN, the drop height was set at 3m and the impact energy will be 6kJ. While simulation numbers 69 and 70 were not axially loaded, the drop height was set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 71 and 72 were axially loaded with a magnitude of 237kN, the drop height was set at 7m and the impact energy will be 14kJ. Moreover, the drop mass had the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

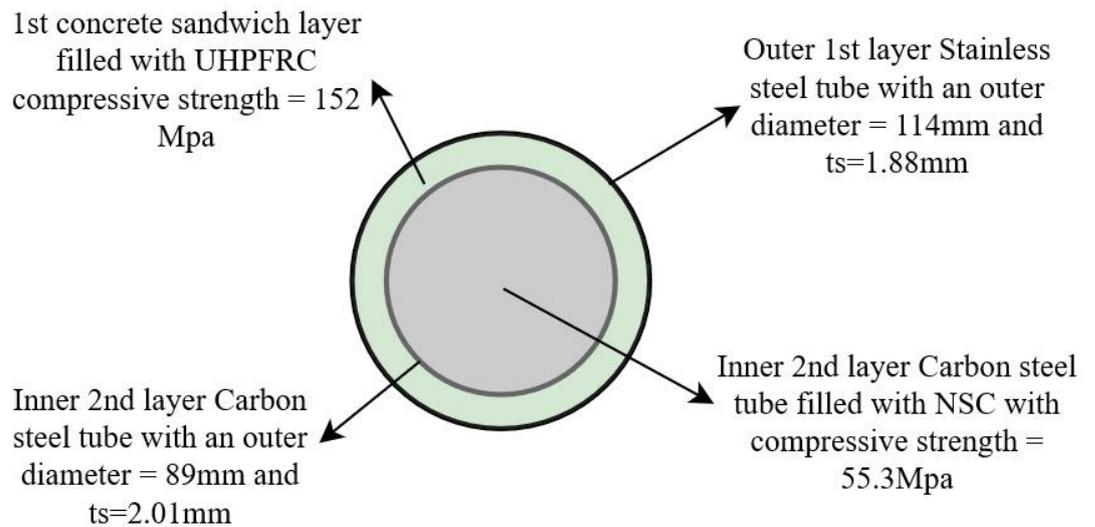


Figure 12. Schematic sketch of CFDST cross section with third modification by [1-3] and material properties for specimens with 89mm outer diameter of the internal tube.

This subsection of the numerical analysis presented the meshing and elements for Concrete Filled Double skin Steel Tubular column members with 1st sandwich layer filled with UHPFRC and internal carbon steel tube filled with NSC under transverse impact load investigation in accordance to the properties stated by [19]. This is including CFDST element, supports, drop hammer and FE model. The numerical meshing and elements of the fourth modeling analysis part for the proposed modification 3 - CFDST with 1st sandwich layer filled with UHPFRC and internal carbon steel tube filled with NSC under transverse impact load investigation was as follows:

- The mesh for both the outer first layer stainless steel tube and the inner second layer carbon steel tube were simulated using S4R 4-node shell elements.
- The mesh for both UHPFRC and NSC were simulated using C3D8R 8-node solid element.

With reference to [19], the mesh for supports was built using R3D4 4-node quadrilateral rigid element. Again, as recommended by [19], the mesh for drop hammer was built using R3D4 4-node quadrilateral rigid element.

5. Author propositions of novel triple skin CFST under the effect of sudden impact

The author of this paper proposes two novel triple skin CFST under the effect of sudden impact. Where the first design proposition is CFTST with 1st sandwich layer filled with UHPFRC and 2nd sandwich layer filled with NSC and the second proposition is CFTST with 1st sandwich layer filled with UHPFRC, 2nd sandwich layer filled with NSC and 3rd skin internal tube filled with NSC.

5.1. First proposition of novel triple skin CFST under the effect of sudden impact - CFTST with 1st sandwich layer filled with UHPFRC and 2nd sandwich layer filled with NSC

The fifth stage of the numerical analysis involves the first novel design proposition of triple skin CFST. Moreover, this stage introduces the first Concrete Filled Triple skinned Steel Tube (CFTST) subjected to sudden impact. Furthermore, this will be carried out by inducing an additional third internal carbon steel tube to the tested specimens by [19]. In addition, this design modification has two concrete fill sandwich layers. The first concrete fill sandwich layer lays between the outer stainless-steel tube and the inner second layer carbon steel tube. Besides, the first concrete fill sandwich layer will be filled with Ultra

High-Performance Fiber Reinforced Polymer (UHPFRC). Furthermore, the second concrete fill sandwich layer lays between the inner second layer carbon steel tube and the inner third layer carbon steel tube. Moreover, the second concrete fill sandwich layer will be filled with Normal Strength Concrete (NSC). Afterwards, the structural behavior will be assisted under transverse impact loading. Moreover, the results obtained will be compared with the experimental results achieved by [19] to determine the percentage of increase in the impact resistivity of the 4th proposed design. As shown in Table 8, the fifth stage of this study consists of eighteen numerical models (simulation numbers 73 to 90). Again, three main variables will be evaluated (diameter of internal carbon steel tube, magnitude of axial load and drop height). In addition, Table 8 presents a detailed list of geometrical properties, cross sectional dimensions and impact loading conditions for the 4th proposed modification on the CF DST specimens carried out by [19]. Besides, the list which presented in Table 8 includes details of the simulation numbers, specimens tag numbers, type of modification for this stage, diameter and thickness of the steel tubes, length of the specimens, magnitude of axial load, drop heights, impact mass, impact energy and geometry and size of indenter.

Table 8. List of geometrical properties, cross sectional dimensions and impact loading conditions for CFTST specimens with first proposition of novel triple skin CFST.

Simulation number	Specimen Tag number	Outer 1st layer Stainless Steel tube		Inner 2nd layer Carbon Steel tube		Inner 3rd layer Carbon Steel tube		L (mm)	Axially Loaded	Magnitude of axial load	H (m)	M0 (kg)	E0 (kJ)
		D (mm)	ts (mm)	D (mm)	ts (mm)	D (mm)	ts (mm)						
73	L-3-0-a-M4	114	1.88	81.32	2.52	48	2.52	1800	No	0	3	203.7	6
74	L-3-0-b-M4	114	1.88	81.32	2.52	48	2.52		No	0	3	203.7	6
75	L-5-0.5-a-M4	114	1.88	81.32	2.52	48	2.52		Yes	343	5	203.7	10
76	L-5-0.5-b-M4	114	1.88	81.32	2.52	48	2.52		Yes	343	5	203.7	10
77	L-7-0.3-a-M4	114	1.88	81.32	2.52	48	2.52		Yes	206	7	203.7	14
78	L-7-0.3-b-M4	114	1.88	81.32	2.52	48	2.52		Yes	206	7	203.7	14
79	M-3-0.5-a-M4	114	1.88	76	2.01	38	2.01		Yes	317	3	203.7	6
80	M-3-0.5-b-M4	114	1.88	76	2.01	38	2.01		Yes	317	3	203.7	6
81	M-5-0.3-a-M4	114	1.88	76	2.01	38	2.01		Yes	190	5	203.7	10
82	M-5-0.3-b-M4	114	1.88	76	2.01	38	2.01		Yes	190	5	203.7	10

83	M-7-0-a-M4	114	1.88	76	2.01	38	2.01	No	0	7	203.7	14
84	M-7-0-b-M4	114	1.88	76	2.01	38	2.01	No	0	7	203.7	14
85	H-3-0.3-a-M4	114	1.88	89	2.01	64	2.01	Yes	142	3	203.7	6
86	H-3-0.3-b-M4	114	1.88	89	2.01	64	2.01	Yes	142	3	203.7	6
87	H-5-0-a-M4	114	1.88	89	2.01	64	2.01	No	0	5	203.7	10
88	H-5-0-b-M4	114	1.88	89	2.01	64	2.01	No	0	5	203.7	10
89	H-7-0.5-a-M4	114	1.88	89	2.01	64	2.01	Yes	237	7	203.7	14
90	H-7-0.5-b-M4	114	1.88	89	2.01	64	2.01	Yes	237	7	203.7	14

Modification 4 - (1) Adding Triple skin details highlighted in blue, (2) Filling the 1st sandwich layer between the Outer 1st layer Stainless Steel tube and the Inner 2nd layer Carbon Steel tube with UHPFRC, (3) Filling the 2nd sandwich layer between the Inner 2nd layer Carbon Steel tube and the Inner 3rd layer Carbon Steel tube with NSC & (4) Keep the Inner 3rd layer Carbon Steel tube hollow and unfilled. Impactor/Indenter geometry and size - drop hammer with 30mm×80mm rectangular bottom surface.

A schematic drawing has been shown in Figure 13 of the CFTST cross section with 4th modification and material properties for specimens with third layer inner steel tube (diameter of 48mm). As can be seen in Figure 13, the model consists of three steel tubes. The first layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second layer inner steel tube represents the additional proposed steel skin and is made from carbon steel with an outer diameter of 81.32mm and a thickness of 2.52mm. Moreover, the third layer inner steel tube is made from carbon steel with an outer diameter of 48mm and tube thickness of 2.52mm. Furthermore, the first concrete fill sandwich layer between the outer stainless-steel tube and the inner second layer carbon steel tube will be filled with Ultra High-Performance Fiber Reinforced Polymer (UHPFRC). Besides the compressive strength of the UHPFRC will be 152MPa with reference to the material properties used by [15-16]. Contrariwise, the second concrete fill sandwich layer between the inner second layer carbon steel tube and the inner third layer carbon steel tube will be filled with Normal Strength Concrete (NSC) - compressive strength of 55.3MPa. Furthermore, the inner third layer carbon steel tube will be unfilled/hollow. Moreover, all the numerically analyzed specimens has a standard length of 1800mm.

This proposed modification design in figure 13 will represent simulation numbers 73 to 78 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 73 and 74 will not be axially load, the drop height will be set at 3m and the impact energy will be 6kJ. While simulation numbers 75 and 76 will be axially loaded with a magnitude of 343kN, the drop height will be set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 77 and 78 will be axially loaded with a magnitude of 206kN, the drop height will be set at 7m and the impact energy will be 14kJ. Moreover, the drop mass will have the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

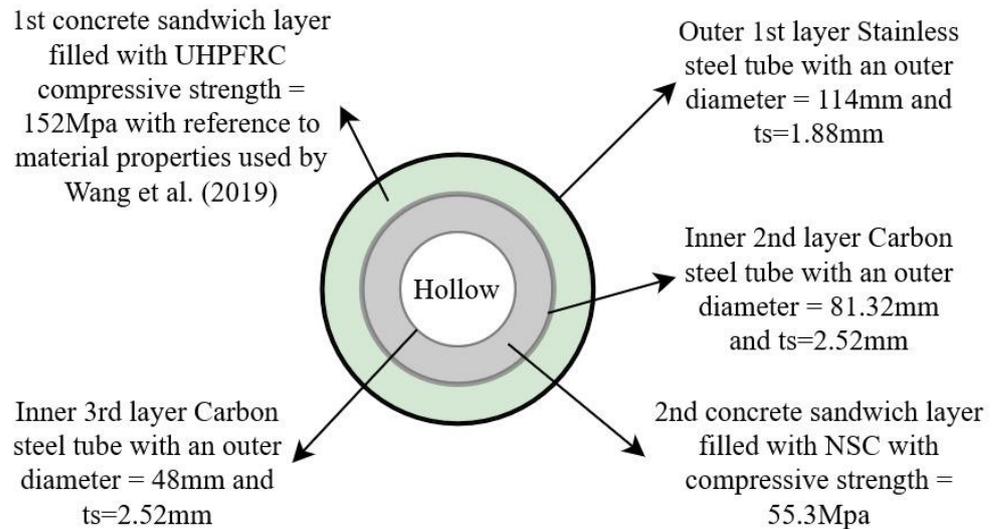


Figure 13. Schematic sketch of the first proposition of novel triple skin CFST and material properties for specimens with an addition 2nd internal tube ($D=81.32\text{mm}$).

A schematic drawing has been shown in Figure 14 of the CFTST cross section with 4th modification and material properties for specimens with third layer inner steel tube (diameter of 48mm). As can be seen in Figure 14, the model consists of three steel tubes. The first layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. Moreover, the second layer inner steel tube is made from carbon steel with an outer diameter of 76mm and a thickness of 2.01mm. On the other hand, the third layer inner steel tube represents the additional proposed steel skin and is made from carbon steel with an outer diameter of 38mm and tube thickness of 2.01mm. Furthermore, the first concrete fill sandwich layer between the outer stainless-steel tube and the inner second layer carbon steel tube will be filled with Ultra High-Performance Fiber Reinforced Polymer (UHPFRC). Besides the compressive strength of the UHPFRC will be 152MPa with reference to the material properties used by [15-16]. Contrariwise, the second concrete fill sandwich layer between the inner second layer carbon steel tube and the inner third layer carbon steel tube will be filled with Normal Strength Concrete (NSC) - compressive strength of 55.3MPa. Furthermore, the inner third layer carbon steel tube will be unfilled/hollow. Moreover, all the numerically analyzed specimens has a standard length of 1800mm.

This design modification in figure 14 will represent simulation numbers 79 to 84 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 79 and 80 will be axially load with a magnitude of 317kN, the drop height will be set at 3m and the impact energy will be 6kJ. While simulation numbers 81 and 82 will be axially loaded with a magnitude of 190kN, the drop height will be set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 83 and 84 will not be axially loaded, the drop height will be set at 7m and the impact energy will be 14kJ. Moreover, the drop mass will have the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

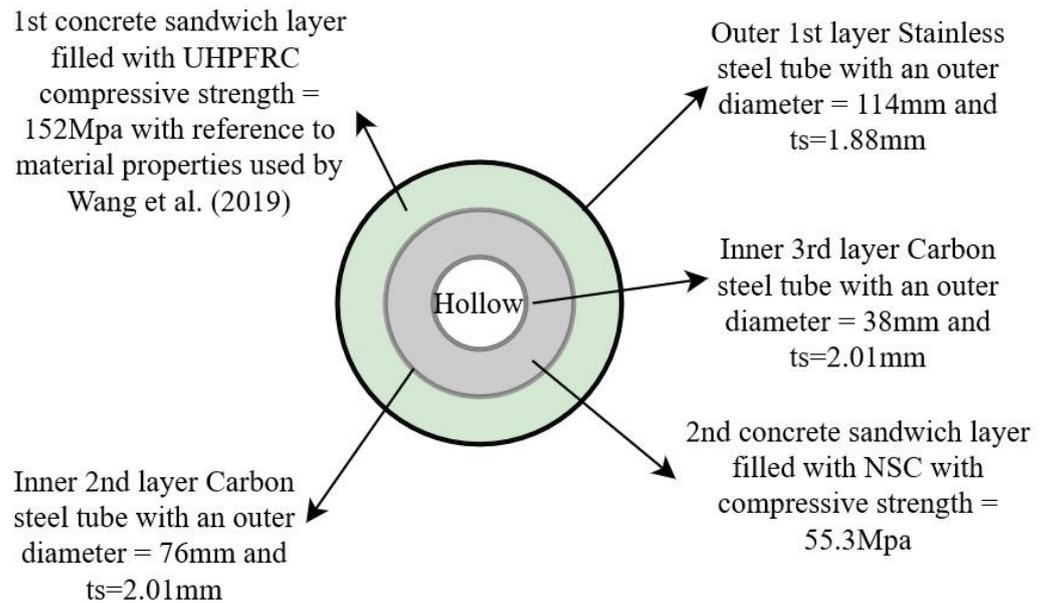


Figure 14. Schematic sketch of the first proposition of novel triple skin CFST and material properties for specimens with an addition 3rd internal tube ($D=38\text{mm}$).

A schematic drawing has been shown in Figure 15 of the CFTST cross section with 4th modification and material properties for specimens with third layer inner steel tube (diameter of 64mm). As can be seen in Figure 15, the model consists of three steel tubes. The first layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. Moreover, the second layer inner steel tube is made from carbon steel with an outer diameter of 89mm and a thickness of 2.01mm. On the other hand, the third layer inner steel tube represents the additional proposed steel skin and is made from carbon steel with an outer diameter of 64mm and tube thickness of 2.01mm. Furthermore, the first concrete fill sandwich layer between the outer stainless-steel tube and the inner second layer carbon steel tube will be filled with Ultra High-Performance Fiber Reinforced Polymer (UHPFRC). Besides the compressive strength of the UHPFRC will be 152MPa with reference to the material properties used by [15-16]. Inversely, the second concrete fill sandwich layer between the inner second layer carbon steel tube and the inner third layer carbon steel tube will be filled with Normal Strength Concrete (NSC) - compressive strength of 55.3MPa. Furthermore, the inner third layer carbon steel tube will be unfilled/hollow. Moreover, all the numerically analyzed specimens has a standard length of 1800mm.

This design modification in figure 15 will represent simulation numbers 85 to 90 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 85 and 86 will be axially load with a magnitude of 142kN, the drop height will be set at 3m and the impact energy will be 6kJ. While simulation numbers 87 and 88 will not be axially loaded, the drop height will be set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 89 and 90 will be axially loaded with a magnitude of 237kN, the drop height will be set at 7m and the impact energy will be 14kJ. Moreover, the drop mass will have the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

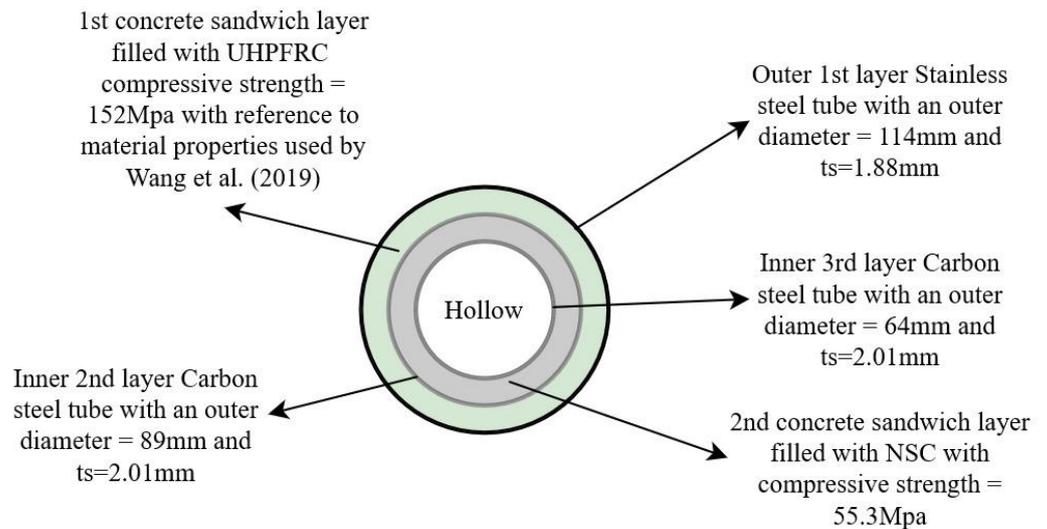


Figure 15. Schematic sketch of the first proposition of novel triple skin CFST and material properties for specimens with an addition 3rd internal tube ($D=64\text{mm}$).

This subsection of the numerical analysis will present the meshing and elements for Concrete Filled Triple skin Steel Tubular column members with 1st sandwich layer filled with UHPFRC and 2nd sandwich layer filled with NSC under transverse impact load investigation in accordance to the properties stated by [19]. Furthermore, this subsection has been divided into four parts (1) CFDST element, (2) supports, (3) drop hammer and (4) FE model. The numerical meshing and elements of the fifth modeling analysis part for the proposed modification 4 - CFTST with 1st sandwich layer filled with UHPFRC and 2nd sandwich layer filled with NSC under transverse impact load investigation will be as follows:

- The mesh for the outer first layer stainless steel tube, the inner second layer carbon steel tube and the inner third layer carbon steel tube will be simulated using S4R 4-node shell elements.
- The mesh for both UHPFRC and NSC sandwich layers will be simulated using C3D8R 8-node solid element.

With reference to [19], the mesh for supports will be built using R3D4 4-node quadrilateral rigid element. Again, as recommended by [19], the mesh for drop hammer was built using R3D4 4-node quadrilateral rigid element.

5.2. Second proposition of novel triple skin CFST under the effect of sudden impact - CFTST with 1st sandwich layer filled with UHPFRC, 2nd sandwich layer filled with NSC and 3rd skin internal tube filled with NSC

The fifth stage of the numerical analysis involves the first novel design proposition of triple skin CFST. In addition, this design modification has three concrete fill sandwich layers. The first concrete fill sandwich layer lays between the outer stainless-steel tube and the inner second layer carbon steel tube. Besides, the first concrete fill sandwich layer will be filled with Ultra High-Performance Fiber Reinforced Polymer (UHPFRC). Furthermore, the second concrete fill sandwich layer lays between the inner second layer carbon steel tube and the inner third layer carbon steel tube. Moreover, the second concrete fill sandwich layer will be filled with Normal Strength Concrete (NSC). Moreover, the third concrete fill sandwich layer will be located in the core of the inner third skin carbon steel tube. In addition, the third concrete fill sandwich layer will be filled with Normal Strength Concrete (NSC). Afterwards, the structural behavior will be assisted under transverse impact loading. Moreover, the results obtained will be compared with the experimental results achieved by [19] to determine the percentage of increase in the impact resistivity of the

5th proposed design. As shown in Table 9, the sixth stage of this study consists of eighteen numerical models (simulation numbers 91 to 108). Again, three main variables will be evaluated (diameter of internal carbon steel tube, magnitude of axial load and drop height). In addition, Table 9 presents a detailed list of geometrical properties, cross sectional dimensions and impact loading conditions for the 5th proposed modification on the CFDST specimens carried out by [19]. Besides, the list which presented in Table 9 includes details of the simulation numbers, specimens tag numbers, type of modification for this stage, diameter and thickness of the steel tubes, length of the specimens, magnitude of axial load, drop heights, impact mass, impact energy and geometry and size of indenter.

Table 9. List of geometrical properties, cross sectional dimensions and impact loading conditions for CFTST specimens with second proposition of novel triple skin CFST.

Simulation number	Specimen Tag number	Outer 1st layer Stainless Steel tube		Inner 2nd layer Carbon Steel tube		Inner 3rd layer Carbon Steel tube		L (mm)	Axially Loaded	Magnitude of axial load (kN)	H (m)	M0 (kg)	E0 (kJ)
		D (mm)	ts (mm)	D (mm)	ts (mm)	D (mm)	ts (mm)						
91	L-3-0-a-M5	114	1.88	81.32	2.52	48	2.52	1800	No	0	3	203.7	6
92	L-3-0-b-M5	114	1.88	81.32	2.52	48	2.52		No	0	3	203.7	6
93	L-5-0.5-a-M5	114	1.88	81.32	2.52	48	2.52		Yes	343	5	203.7	10
94	L-5-0.5-b-M5	114	1.88	81.32	2.52	48	2.52		Yes	343	5	203.7	10
95	L-7-0.3-a-M5	114	1.88	81.32	2.52	48	2.52		Yes	206	7	203.7	14
96	L-7-0.3-b-M5	114	1.88	81.32	2.52	48	2.52		Yes	206	7	203.7	14
97	M-3-0.5-a-M5	114	1.88	76	2.01	38	2.01		Yes	317	3	203.7	6
98	M-3-0.5-b-M5	114	1.88	76	2.01	38	2.01		Yes	317	3	203.7	6
99	M-5-0.3-a-M5	114	1.88	76	2.01	38	2.01		Yes	190	5	203.7	10

100	M-5-0.3-b-M5	114	1.88	76	2.01	38	2.01	Yes	190	5	203.7	10
101	M-7-0-a-M5	114	1.88	76	2.01	38	2.01	No	0	7	203.7	14
102	M-7-0-b-M5	114	1.88	76	2.01	38	2.01	No	0	7	203.7	14
103	H-3-0.3-a-M5	114	1.88	89	2.01	64	2.01	Yes	142	3	203.7	6
104	H-3-0.3-b-M5	114	1.88	89	2.01	64	2.01	Yes	142	3	203.7	6
105	H-5-0-a-M5	114	1.88	89	2.01	64	2.01	No	0	5	203.7	10
106	H-5-0-b-M5	114	1.88	89	2.01	64	2.01	No	0	5	203.7	10
107	H-7-0.5-a-M5	114	1.88	89	2.01	64	2.01	Yes	237	7	203.7	14
108	H-7-0.5-b-M5	114	1.88	89	2.01	64	2.01	Yes	237	7	203.7	14

Modification 5 - All the modifications as in modification 4 + Filling the Inner 3rd layer Carbon Steel tube with NSC.

Impactor/Indenter geometry and size - drop hammer with 30mm×80mm rectangular bottom surface.

A schematic drawing has been shown in Figure 16 of the CFTST cross section with 5th modification and material properties for specimens with third layer inner steel tube (diameter of 48mm). As can be seen in Figure 16, the model consists of three steel tubes. The first layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. On the other hand, the second layer inner steel tube represents the additional proposed steel skin and is made from carbon steel with an outer diameter of 81.32mm and a thickness of 2.52mm. Moreover, the third layer inner steel tube is made from carbon steel with an outer diameter of 48mm and tube thickness of 2.52mm. Furthermore, the first concrete fill sandwich layer between the outer stainless-steel tube and the inner second layer carbon steel tube will be filled with Ultra High-Performance Fiber Reinforced Polymer (UHPFRC). Besides the compressive strength of the UHPFRC will be 152MPa with reference to the material properties used by [15-16]. Contrariwise, the second concrete fill sandwich layer between the inner second layer carbon steel tube and the inner third layer carbon steel tube will be filled with Normal Strength Concrete (NSC) - compressive strength of 55.3MPa. Also, the inner third layer carbon steel tube will be filled with Normal Strength Concrete (NSC) - compressive strength of 55.3MPa. Moreover, all the numerically analyzed specimens has a standard length of 1800mm.

This proposed modification design in figure 16 will represent simulation numbers 91 to 96 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 91 and 92 will not be axially load, the drop height will be set at 3m and the impact energy will be 6kJ. While simulation numbers 93 and 94 will be axially loaded with a magnitude of 343kN, the drop height will be set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 95 and 96 will be axially loaded with a magnitude of 206kN, the drop height will be set at 7m and the impact energy will be 14kJ. Moreover, the drop mass will have the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

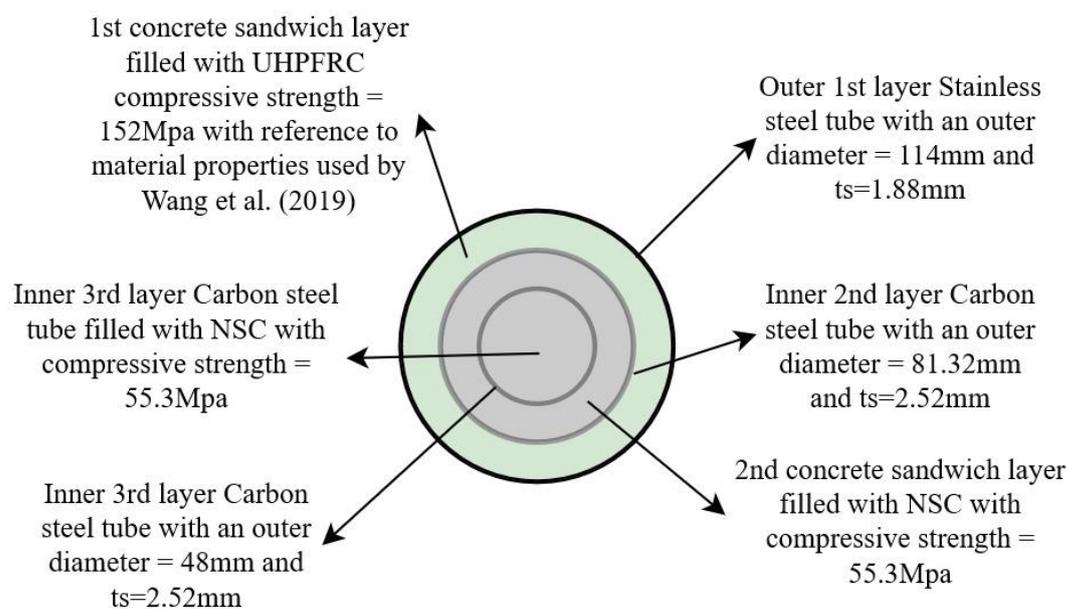


Figure 16. Schematic sketch of the second proposition of novel triple skin CFST and material properties for specimens with an addition 2nd internal tube ($D=81.32$ mm).

A schematic drawing has been shown in Figure 17 of the CFTST cross section with 5th modification and material properties for specimens with third layer inner steel tube (diameter of 38mm). As can be seen in Figure 17, the model consists of three steel tubes. The first layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. Moreover, the second layer inner steel tube is made from carbon steel with an outer diameter of 76mm and a thickness of 2.01mm. On the other hand, the third layer inner steel tube represents the additional proposed steel skin and is made from carbon steel with an outer diameter of 38mm and tube thickness of 2.01mm. Furthermore, the first concrete fill sandwich layer between the outer stainless-steel tube and the inner second layer carbon steel tube will be filled with Ultra High-Performance Fiber Reinforced Polymer (UHPFRC). Besides the compressive strength of the UHPFRC will be 152MPa with reference to the material properties used by [15-16]. Contrariwise, the second concrete fill sandwich layer between the inner second layer carbon steel tube and the inner third layer carbon steel tube will be filled with Normal Strength Concrete (NSC) - compressive strength of 55.3MPa. Also, the inner third layer carbon steel tube will be filled with Normal Strength Concrete (NSC) - compressive strength of 55.3MPa. Moreover, all the numerically analyzed specimens has a standard length of 1800mm.

This design modification in figure 17 will represent simulation numbers 97 to 102 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 97 and 98 will be axially load with a magnitude of 317kN, the drop

height will be set at 3m and the impact energy will be 6kJ. While simulation numbers 99 and 100 will be axially loaded with a magnitude of 190kN, the drop height will be set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 101 and 102 will not be axially loaded, the drop height will be set at 7m and the impact energy will be 14kJ. Moreover, the drop mass will have the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

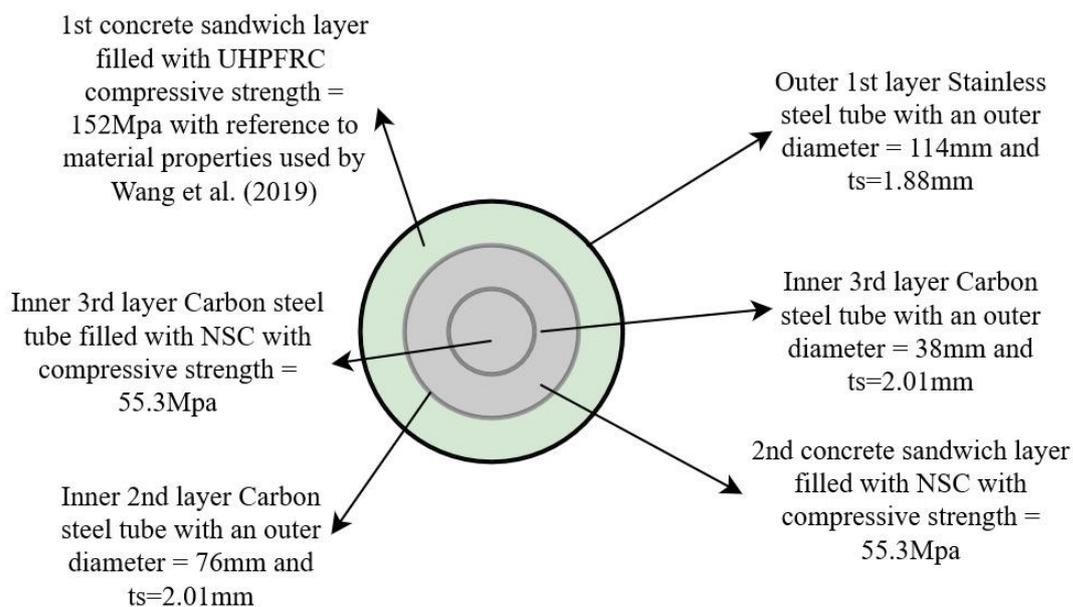


Figure 17. Schematic sketch of the second proposition of novel triple skin CFST and material properties for specimens with an addition 3rd internal tube ($D=38\text{mm}$).

A schematic drawing has been shown in Figure 18 of the CFTST cross section with 5th modification and material properties for specimens with third layer inner steel tube (diameter of 64mm). As can be seen in Figure 18, the model consists of three steel tubes. The first layer outer steel tube is made from stainless steel with an outer diameter of 114mm with a tube thickness of 1.88mm. Moreover, the second layer inner steel tube is made from carbon steel with an outer diameter of 89mm and a thickness of 2.01mm. On the other hand, the third layer inner steel tube represents the additional proposed steel skin and is made from carbon steel with an outer diameter of 64mm and tube thickness of 2.01mm. Furthermore, the first concrete fill sandwich layer between the outer stainless-steel tube and the inner second layer carbon steel tube will be filled with Ultra High-Performance Fiber Reinforced Polymer (UHPFRC). Besides the compressive strength of the UHPFRC will be 152MPa with reference to the material properties used by [15-16]. Inversely, the second concrete fill sandwich layer between the inner second layer carbon steel tube and the inner third layer carbon steel tube will be filled with Normal Strength Concrete (NSC) - compressive strength of 55.3MPa. Also, the inner third layer carbon steel tube will be filled with Normal Strength Concrete (NSC) - compressive strength of 55.3MPa. Moreover, all the numerically analyzed specimens has a standard length of 1800mm.

This design modification in figure 18 will represent simulation numbers 103 to 108 with variations in magnitude of axial load, drop height and impact energy. For example, simulations number 103 and 104 will be axially load with a magnitude of 142kN, the drop height will be set at 3m and the impact energy will be 6kJ. While simulation numbers 105 and 106 will not be axially loaded, the drop height will be set at 5m and the impact energy will be around 10kJ. Furthermore, simulation numbers 107 and 108 will be axially loaded

with a magnitude of 237kN, the drop height will be set at 7m and the impact energy will be 14kJ. Moreover, the drop mass will have the same magnitude for all the simulations with a value of 203.7Kg. Finally, the geometry of the bottom surface of the drop hammer indenter is rectangular and with a parameter of 30mm by 80mm.

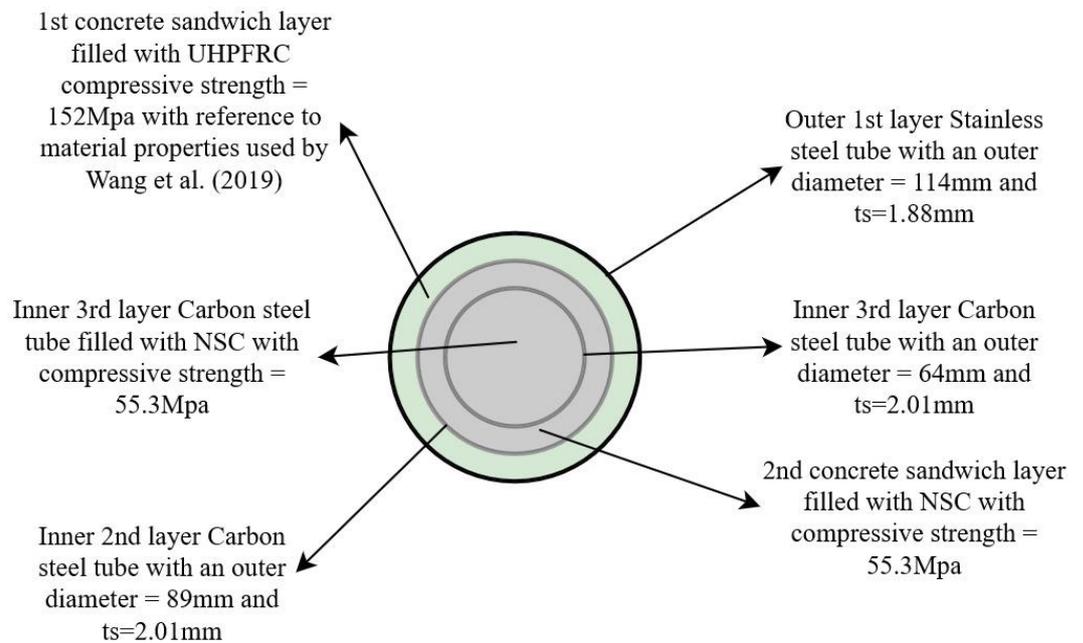


Figure 18. Schematic sketch of the second proposition of novel triple skin CFST and material properties for specimens with an addition 3rd internal tube ($D=64\text{mm}$).

This subsection of the numerical analysis will present the meshing and elements for Concrete Filled Triple skin Steel Tubular column members with 1st sandwich layer filled with UHPFRC, 2nd sandwich layer filled with NSC and 3rd skin internal tube filled with NSC under transverse impact load investigation in accordance to the properties stated by [19]. Furthermore, this subsection has been divided into four parts (1) CFDST element, (2) supports, (3) drop hammer and (4) FE model. The numerical meshing and elements of the sixth modeling analysis part for the proposed modification 5 - CFTST with 1st sandwich layer filled with UHPFRC, 2nd sandwich layer filled with NSC and 3rd skin internal tube filled with NSC under transverse impact load investigation will be as follows:

- The mesh for the outer first layer stainless steel tube, the inner second layer carbon steel tube and the inner third layer carbon steel tube will be simulated using S4R 4-node shell elements.
- The mesh for both UHPFRC and NSC sandwich and core layers will be simulated using C3D8R 8-node solid element.

With reference to [19], the mesh for supports will be built using R3D4 4-node quadrilateral rigid element. Again, as recommended by [19], the mesh for drop hammer was built using R3D4 4-node quadrilateral rigid element. Moreover, figure 19 presents the novel triple skin CFST, where (a) is the Model and (b) is elements and mesh. Finally, figure 20 illustrates the proposed triple skin CFST numerical model under the effect of sudden impact. Where RP-1 demonstrates the drop hammer which initiates the sudden impact.

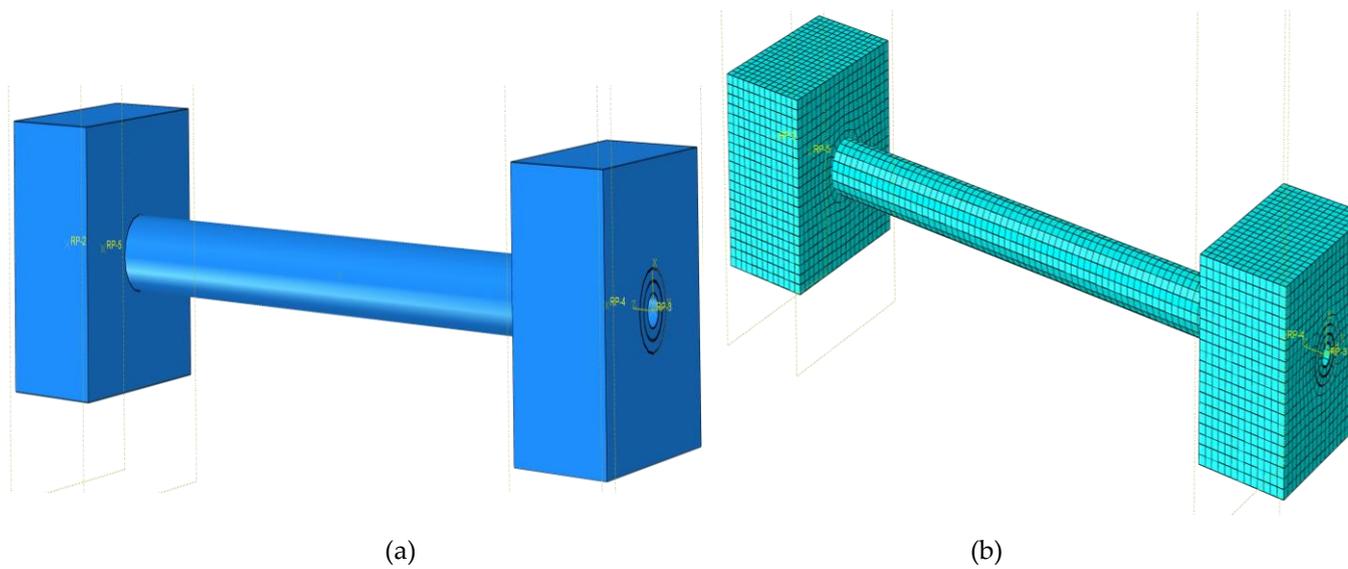
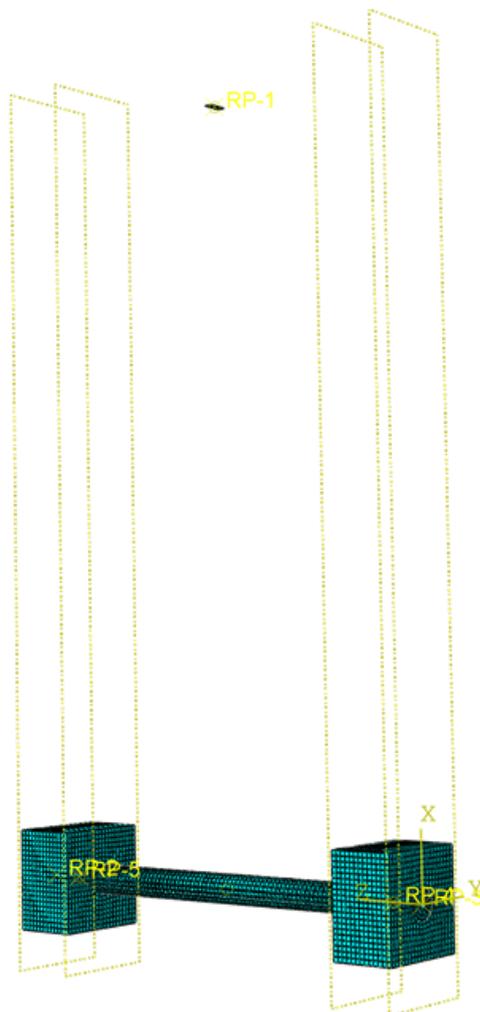


Figure 19. Novel Triple Skin Concrete Filled Steel Tubes (TSCFST), where (a) Proposed Model; (b) Elements and meshing.

Figure 20. Novel triple skin CFST numerical model under the effect of sudden impact.



6. Conclusions

This paper is a continuation of the researches which were carried out by [1-3]. Consequently, this research proposes analytical analysis of two novel triple skin Concrete Filled Steel Tube (CFST) designs under the effect of sudden impact. It is strongly believed that both the first and the second propositions of novel triple skin CFST will enhance the global impact resistivity of the structural member when comparing with the experimental and numerical double skin CFST models by [1-3] and [19]. Accordingly, the below has been concluded:

- The first proposition of novel triple skin CFST will increase the impact resistivity of the structural member by 25 to 32%.
- The second proposition of novel triple skin CFST will boost the efficiency of the structural member under the event of sudden impact by 28 to 36%.
- Both the first and second triple skin CFST propositions will reduce the residual and maximum displacements by up to 15% when compared with double skin CFST members.
- The diameter of the triple internal carbon steel tube has a direct relationship with residual displacements after sudden impact. For instance, the higher the diameter results in higher maximum and residual displacements.
- By filling the third triple skin tube with Normal Strength Concrete (NSC), the displacements after impact reduces by up to 12%.

In accordance to the above observations, the author of this paper proposes further numerical investigations on the impact behavior of triple skin stainless steel tubular columns filled with UHPFRC and externally reinforced with Glass Fiber Reinforced Polymer (GFRP).

Conflicts of Interest: “The author declares no conflict of interest.”

References

- [1] Abdel Rahim, K. A. N. (2021) Literature Review: Concrete Filled Steel Tubes Under Transverse Impact Loading, *Current Trends in Civil & Structural Engineering* 7(3).
- [2] Abdel Rahim, K. A. N. (2021) Numerical Modelling of the Behavior of Steel-Concrete Composite Columns of Different Types of Circular Cross Section Subject to Lateral Impact, *Civil Engineering Research Journal* 11(5).
- [3] Abdel Rahim, K. A. N. (2021) Circular double skin stainless steel tubular column filled with UHPFRC subjected to impact load, *Global Journal of Civil Engineering*, Vol. 02 (2021) pp 1-11.
- [4] Alam, M, I; Fawzia, S.; Zhao, X, L.; Remennikov, A.; M, Bambach.; M, R.; Elchalakani, M. (2017) Performance and dynamic behaviour of FRP strengthened CFST members subjected to lateral impact, *Engineering Structures* 147: pp 160–176.
- [5] Bambach, M, R.; (2011) Design of hollow and concrete filled steel and stainless steel tubular columns for transverse impact loads. *ThinWalled Structures* 49 (10): pp 1251–1260.
- [6] Abaqus (2007) ABAQUS Standard User’s Manual, Version 6.7. Providence, RI, *Dassault Systèmes Corp*, USA.
- [7] Han LH, Yao G, Tao Z (2007) Performance of concrete-filled thin-walled steel tubes under pure torsion. *Thin Wall Structures* 45(1): 24-36.
- [8] Hibbitt, Karlsson, Sorensen Inc (2010) *ABAQUS Standard User’s manual*. Version 6.10. RI, USA.
- [9] Hou CC, Han LH (2018) Life-cycle performance of deteriorated concrete-filled steel tubular (CFST) structures subject to lateral impact. *Thin-Walled Structures* 132: 362-374.
- [10] Karlsson Sorensen Inc. Hibbitt. (2005), *ABAQUS/Explicit User’s Manual*. New York: Rhode Island; [Version 6.5.1].
- [11] Liu FQ, Gardner L, Yang H (2014) Post-fire behaviour of reinforced concrete stub columns confined by circular steel tubes. *Journal of Constructional Steel Research* 102: 82-103.
- [12] Othman H, Marzouk H (2018) Applicability of damage plasticity constitutive model for ultra-high performance fibre-reinforced concrete under impact loads. *International Journal of Impact Engineering* 114: 20-31.
- [13] Tao Z, Wang Z B, Yu Q, 2013, Finite element modelling of concrete-filled steel stub columns under axial compression, *Journal of Constructional Steel Research* 89: pp 121–131.
- [14] Wang R, Han LH, Hou CC (2013) Behavior of concrete filled steel tubular (CFST) members under lateral impact: Experiment and FEA model. *Journal of Constructional Steel Research* 80: 188-201.
- [15] Wang W, Wu C, Li J, Liu Z, Lv Y (2019) Behavior of ultra-high-performance fiber-reinforced concrete (UHPFRC) filled steel tubular members under lateral impact loading. *International Journal of Impact Engineering* 132: 103314.

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- [16] Wang W, Wu C, Liu Z (2019) Compressive behavior of hybrid doubleskin tubular columns with ultra-high-performance fiber-reinforced concrete (UHPFRC). *Engineering Structures* 180: 419-441.
 - [17] Yang YF, Zhang ZC, Fu F (2015) Experimental and numerical study on square RACFST members under lateral impact loading. *Journal of Constructional Steel Research* 111: 43-56.
 - [18] Yousuf M, Uy B, Tao Z, Remennikov A, Liew JYR (2013) Transverse impact resistance of hollow and concrete filled stainless steel columns. *Journal of Constructional Steel Research* 82: 177-189.
 - [19] Zhao, H.; Wang, R.; Hou, C.; Lam, D. (2019) Performance of circular CFDST members with external stainless-steel tube under transverse impact loading, *Thin-Walled Structures* 145: 106380.